THE POPULAR SCIENCE MONTHLY.

FEBRUARY, 1904.

SCIENTIFIC INVESTIGATION AND PROGRESS.*

BY PRESIDENT IRA REMSEN,
JOHNS HOPKINS UNIVERSITY.

AT the weekly services of many of our churches it is customary to begin with the reading of a verse or two from the Scriptures for the purpose, I suppose, of putting the congregations in the proper state of mind for the exercises which are to follow. It seems to me that we may profit by this example, and accordingly I ask your attention to Article I. of the Constitution of the American Association for the Advancement of Science, which reads thus: 'The objects of the association are, by periodical and migratory meetings, to promote intercourse between those who are cultivating science in different parts of America, to give stronger and more general impulse and more systematic direction to scientific research, and to procure for the labors of scientific men increased facilities and a wider usefulness.'

The first object mentioned, you will observe, is 'to promote intercourse between those who are cultivating science in different parts of America'; the second is 'to give a stronger and more general impulse and more systematic direction to scientific research'; and the third is 'to procure for the labors of scientific men increased facilities and a wider usefulness.' Those who are familiar with the history of the association are well aware that it has served its purposes admirably, and I am inclined to think that those who have been in the habit of attending the meetings will agree that the object which appeals to them most strongly is the promotion of intercourse between those who are cultivating science. Given this intercourse and the other objects

* Address of the retiring president of the American Association for the Advancement of Science, St. Louis meeting, December 28, 1903.

will be reached as a necessary consequence, for the intercourse stimulates thought, and thought leads to work, and work leads to wider usefulness.

While in 1848, when the association was organized and the constitution was adopted, there was a fair number of good scientific investigators in this country, it is certain that in the half century that has passed since then the number of investigators has increased very largely, and naturally the amount of scientific work done at present is very much greater than it was at that time. So great has been the increase in scientific activity during recent years that we are apt to think that by comparison scientific research is a new acquisition. In fact there appears to be an impression abroad that in the world at large scientific research is a relatively new thing, for which we of this generation and our immediate predecessors are largely responsible. Only a superficial knowledge of the history of science is necessary, however, to show that the sciences have been developed slowly, and that their beginnings are to be looked for in the very earliest times. Everything seems to point to the conclusion that men have always been engaged in efforts to learn more and more in regard to the world in which they find themselves. Sometimes they have been guided by one motive and sometimes by another, but the one great underlying motive has been the desire to get a clearer and clearer understanding of the universe. But besides this there has been the desire to find means of increasing the comfort and happiness of the human race.

A reference to the history of chemistry will serve to show how these motives have operated side by side. One of the first great incentives for working with chemical things was the thought that it was possible to convert base metals like lead and copper into the so-called noble metals, silver and gold. Probably no idea has ever operated as strongly as this upon the minds of men to lead them to undertake chemical experiments. It held control of intellectual men for centuries and it was not until about a hundred years ago that it lost its hold. It is very doubtful if the purely scientific question whether one form of matter can be transformed into another would have had the power to control the activities of investigators for so long a time; and it is idle to speculate upon this subject. It should, however, be borne in mind that many of those who were engaged in this work were actuated by a desire to put money in their purses—a desire that is by no means to be condemned without reserve, and I mention it not for the purpose of condemning it, but to show that a motive that we sometimes think of as peculiarly modern is among the oldest known to man.

While the alchemists were at work upon their problems, another class of chemists were engaged upon problems of an entirely different nature. The fact that substances obtained from various natural

sources and others made in the laboratory produce effects of various kinds when taken into the system led to the thought that these substances might be useful in the treatment of disease. Then, further, it was thought that disease itself is a chemical phenomenon. These thoughts, as is evident, furnish strong motives for the investigation of chemical substances, and the science of chemistry owes much to the work of those who were guided by these motives.

And so in each period as a new thought has served as the guide we find that men have been actuated by different motives, and often one and the same worker has been under the influence of mixed motives. Only in a few cases does it appear that the highest motives alone operate. We must take men as we find them, and we may be thankful that on the whole there are so many who are impelled by one motive or another or by a mixture of motives to take up the work of investigating the world in which we live. Great progress is being made in consequence and almost daily we are called upon to wonder at some new and marvelous result of scientific investigation. It is quite impossible to make predictions of value in regard to what is likely to be revealed to us by continued work, but it is safe to believe that in our efforts to discover the secrets of the universe only a beginning has been made. No matter in what direction we may look we are aware of great unexplored territories, and even in those regions in which the greatest advances have been made it is evident that the knowledge gained is almost insignificant as compared with that which remains to be learned. But this line of thought may lead to a condition bordering on hopelessness and despondency, and surely we should avoid this condition, for there is much greater cause for rejoicing than for despair. Our successors will see more and see more clearly than we do, just as we see more and see more clearly than our predecessors. It is our duty to keep the work going without being too anxious to weigh the results on an absolute scale. It must be remembered that the absolute scale is not a very sensitive instrument, and that it requires the results of generations to affect it markedly.

On an occasion of this kind it seems fair to ask the question: What does the world gain by scientific investigation? This question has often been asked and often answered, but each answer differs in some respects from the others and each may be suggestive and worth giving. The question is a profound one, and no answer that can be given would be satisfactory. In general it may be said that the results of scientific investigation fall under three heads—the material, the intellectual and the ethical.

The material results are the most obvious and they naturally receive the most attention. The material wants of man are the first to receive consideration. They can not be neglected. He must have food and

clothing, the means of combating disease, the means of transportation, the means of producing heat and a great variety of things that contribute to his bodily comfort and gratify his esthetic desires. It is not my purpose to attempt to deal with all of these and to show how science is helping to work out the problems suggested. I shall have to content myself by pointing out a few of the more important problems the solution of which depends upon the prosecution of scientific research.

First, the food problem. Whatever views one may hold in regard to that which has come to be called 'race suicide,' it appears that the population of the world is increasing rapidly. The desirable places have been occupied. In some parts of the earth there is such a surplus of population that famines occur from time to time, and in other parts epidemics and floods relieve the embarrassment. We may fairly look forward to the time when the whole earth will be overpopulated unless the production of food becomes more scientific than it now is. Here is the field for the work of the agricultural chemist who is showing us how to increase the yield from a given area, and, in case of poor and worn-out soils, how to preserve and increase their fertility. It appears that the methods of cultivating the soil are still comparatively crude, and more and more thorough investigation of the processes involved in the growth of plants is called for. Much has been learned since Liebig founded the science of agricultural chemistry. It was he who pointed out some of the ways by which it is possible to increase the fertility of a soil. Since the results of his investigations were given to the world the use of artificial fertilizers has become more and more general.

But it is one thing to know that artificial fertilizers are useful and it is quite another thing to get them. At first bone dust and guano were chiefly used. Then as these became dearer, phosphates and potassium salts from the mineral kingdom came into use.

At the Fifth International Congress for Applied Chemistry, held at Berlin, Germany, last June, Dr. Adolph Frank, of Charlottenburg, gave an extremely interesting address on the subject of the use of the nitrogen of the atmosphere for agriculture and the industries, which bears upon the problem that we are dealing with. Plants must have nitrogen. At present this is obtained from the great beds of saltpeter found on the west coast of South America—the so-called Chili saltpeter—and also from the ammonia obtained as a by-product in the distillation of coal, especially in the manufacture of coke. The use of Chili saltpeter for agricultural purposes began about 1860. In 1900 the quantity exported was 1,453,000 tons, and its value was about $60,000,000. In the same year the world's production of ammonium sulphate was about 500,000 tons, of a value of somewhat more than $20,000,000. Of these enormous quantities about three quarters finds

application in agriculture. The use of these substances, especially of saltpeter, is increasing rapidly. At present it seems that the successful cultivation of the soil is dependent upon the use of nitrates, and the supply of nitrates is limited. Unless something is done we may look forward to the time when the earth, for lack of proper fertilizers, will not be able to produce as much as it now does, and meanwhile the demand for food is increasing. According to the most reliable estimations indeed the saltpeter beds will be exhausted in thirty or forty years. Is there a way out? Dr. Frank shows that there is. In the air there is nitrogen enough for all. The plants can make only a limited use of this directly. For the most part it must be in some form of chemical combination as, for example, a nitrate or ammonia. The conversion of atmospheric nitrogen into nitric acid would solve the problem, and this is now carried out. But Dr. Frank shows that there is another, perhaps more economical, way of getting the nitrogen into a form suitable for plant food. Calcium carbide can now be made without difficulty and is made in enormous quantities by the action of a powerful electric current upon a mixture of coal and lime. This substance has the power of absorbing nitrogen from the air, and the product thus formed appears to be capable of giving up its nitrogen to plants, or, in other words, to be a good fertilizer. It is true that this subject requires further investigation, but the results thus far obtained are full of promise. If the outcome should be what we have reason to hope, we may regard the approaching exhaustion of the saltpeter beds with equanimity. But, even without this to pin our faith to, we have the preparation of nitric acid from the nitrogen and oxygen of the air to fall back upon.

While speaking of the food problem, a few words in regard to the artificial preparation of foodstuffs. I am sorry to say that there is not much of promise to report upon in this connection. In spite of the brilliant achievements of chemists in the field of synthesis it remains true that thus far they have not been able to make, except in very small quantities, substances that are useful as foods, and there is absolutely no prospect of this result being reached within a reasonable time. A few years ago Berthelot told us of a dream he had had. This has to do with the results that, according to Berthelot, are to be brought about by the advance of chemistry. The results of investigations already accomplished indicate that, in the future, methods will perhaps be devised for the artificial preparation of food from the water and carbonic acid so abundantly supplied by nature. Agriculture will then become unnecessary, and the landscape will not be disfigured by crops growing in geometrical figures. Water will be obtained from holes three or four miles deep in the earth, and this water will be above the boiling temperature, so that it can be used as a source of energy. It will be

obtained in liquid form after it has undergone a process of natural distillation, which will free it from all impurities, including, of course, disease germs. The foods prepared by artificial methods will also be free from microbes, and there will consequently be less disease than at present. Further, the necessity for killing animals for food will no longer exist, and mankind will become gentler and more amenable to higher influences. There is, no doubt, much that is fascinating in this line of thought, but whether it is worth following, depends upon the fundamental assumption. Is it at all probable that chemists will ever be able to devise methods for the artificial preparation of foodstuffs? I can only say that to me it does not appear probable in the light of the results thus far obtained. I do not mean to question the probability of the ultimate synthesis of some of those substances that are of value as foods. This has already been accomplished on the small scale, but for the most part the synthetical processes employed have involved the use of substances which themselves are the products of natural processes. Thus, the fats can be made, but the substances from which they are made are generally obtained from nature and are not themselves synthetical products. Emil Fischer has, to be sure, made very small quantities of sugars of different kinds, but the task of building up a sugar from the raw material furnished by nature—that is to say, from carbonic acid and water—presents such difficulties that it may be said to be practically impossible.

When it comes to starch, and the proteids which are the other chief constituents of foodstuffs, the difficulties are still greater. There is not a suggestion of the possibility of making starch artificially, and the same is true of the proteids. In this connection it is, however, interesting to note that Emil Fischer, after his remarkable successes in the sugar group and the uric acid group, is now advancing upon the proteids. I have heard it said that at the beginning of his career he made out a program for his life work. This included the solution of three great problems. These are the determination of the constitution of uric acid, of the sugars and of the proteids. Two of these problems have been solved. May he be equally successful with the third! Even if he should be able to make a proteid, and show what it is, the problem of the artificial preparation of foodstuffs will not be solved. Indeed, it will hardly be affected.

Although science is not likely, within periods that we may venture to think of, to do away with the necessity of cultivating the soil, it is likely to teach us how to get more out of the soil than we now do, and thus put us in a position to provide for the generations that are to follow us. And this carries with it the thought that, unless scientific investigation is kept up, these coming generations will be unprovided for.

Another way by which the food supply of the world can be increased is by relieving tracts of land that are now used for other purposes than the cultivation of foodstuffs. The most interesting example of this kind is that presented by the cultivation of indigo. There is a large demand for this substance, which is plainly founded upon esthetic desires of a somewhat rudimentary kind. Whatever the cause may be, the demand exists, and immense tracts of land have been and are still, devoted to the cultivation of the indigo plant. Within the past few years scientific investigation has shown that indigo can be made in the factory from substances, the production of which does not for the most part involve the cultivation of the soil. In 1900, according to the report of Dr. Brunck, Managing Director of the Badische Anilin- and Soda-Fabrik, the quantity of indigo produced annually in the factory 'would require the cultivation of an area of more than a quarter of a million acres of land (390 square miles) in the home of the indigo plant.' Dr. Brunck adds: "The first impression which this fact may be likely to produce, is that the manufacture of indigo will cause a terrible calamity to arise in that country; but, perhaps not. If one recalls to mind that India is periodically afflicted with famine, one ought not, without further consideration, to cast aside the hope that it might be good fortune for that country if the immense areas now devoted to a crop which is subject to many vicissitudes and to violent market changes were at last to be given over to the raising of breadstuffs and other food products." "For myself," says Dr. Brunck, "I do not assume to be an impartial adviser in this matter, but, nevertheless, I venture to express my conviction that the government of India will be rendering a very great service if it should support and aid the progress, which will in any case be irresistible, of this impending change in the cultivation of that country, and would support and direct its methodical and rational execution."

The connection between scientific investigation and health is so frequently the subject of discussion that I need not dwell upon it here. The discovery that many diseases are due primarily to the action of microscopic organisms that find their way into the body and produce the changes that reveal themselves in definite symptoms is a direct consequence of the study of the phenomenon of alcoholic fermentation by Pasteur. Everything that throws light upon the nature of the action of these microscopic organisms is of value in dealing with the great problem of combating disease. It has been established in a number of cases that they cause the formation of products that act as poisons and that the diseases are due to the action of these poisons. So also, as is well known, investigation has shown that antidotes to some of these poisons can be produced, and that by means of these antidotes the diseases can be controlled. But more important than this is the discovery

of the way in which diseases are transmitted. With this knowledge it is possible to prevent the diseases. The great fact that the death rate is decreasing stands out prominently and proclaims to humanity the importance of scientific investigation. It is, however, to be noted in this connection that the decrease in the death rate compensates to some extent for the decrease in the birth rate, and that, if an increase in population is a thing to be desired, the investigations in the field of sanitary science are contributing to this result.

The development of the human race is dependent not alone upon a supply of food but upon a supply of energy in available forms. Heat and mechanical energy are absolutely essential to man. The chief source of the energy that comes into play is fuel. We are primarily dependent upon the coal supply for the continuation of the activities of man. Without this, unless something is to take its place, man is doomed. Statistics in regard to the coal supply and the rate at which it is being used have so frequently been presented by those who have special knowledge of this subject that I need not trouble you with them now. The only object in referring to it is to show that, unless by means of scientific investigation man is taught new methods of rendering the world's store of energy available for the production of heat and of motion, the age of the human race is measured by the extent of the supply of coal and other forms of fuel. By other forms of fuel I mean, of course, wood and oil. Plainly, as the demand for land for the production of foodstuffs increases, the amount available for the production of wood must decrease, so that wood need not be taken into account for the future. In regard to oil, our knowledge is not sufficient to enable us to make predictions of any value. If one of the theories now held in regard to the source of petroleum should prove to be correct, the world would find much consolation in it. According to this theory petroleum is not likely to be exhausted, for it is constantly being formed by the action of water upon carbides that in all probability exist in practically unlimited quantity in the interior of the earth. If this be true, then the problem of supplying energy may be reduced to one of transportation of oil. But given a supply of oil and, of course, the problem of transportation is solved.

What are the other practical sources of energy? The most important is the fall of water. This is being utilized more and more year by year since the methods of producing electric currents by means of the dynamo have been worked out. There is plainly much to be learned before the energy made available in the immediate neighborhood of the waterfall can be transported long distances economically, but advances are being made in this line, and already factories that have hitherto been dependent upon coal are making use of the energy derived from waterfalls. The more rapidly these advances take place

the less will be the demand for coal, and if there were enough waterfalls conveniently situated, there would be no difficulty in furnishing all the energy needed by man for heat or for motion.

It is a fortunate thing that, as the population of the earth increases, man's tastes become more complex. If only the simplest tastes prevailed, only the simplest occupations would be called for. But let us not lose time in idle speculations as to the way this primitive condition of things would affect man's progress. As a matter of fact his tastes are becoming more complex. Things that are not dreamed of in one generation become the necessities of the next generation. Many of these things are the direct results of scientific investigation. No end of examples will suggest themselves. Let me content myself by reference to one that has of late been the subject of much discussion. The development of the artificial dye-stuff industries is extremely instructive in many ways. The development has been the direct result of the scientific investigation of things that seemed to have little, if anything, to do with this world. Many thousands of workmen are now employed, and many millions of dollars are invested, in the manufacture of dye-stuffs that were unknown a few years ago. Here plainly the fundamental fact is the esthetic desire of man for colors. A colorless world would be unbearable to him. Nature accustoms him to color in a great variety of combinations, and it becomes a necessity to him. And his desires increase as they are gratified. There seems to be no end to development in this line. At all events, the data at our disposal justify the conclusion that there will be a demand for every dye that combines the qualities of beauty and durability. Thousands of scientifically trained men are engaged in work in the effort to discover new dyes to meet the increasing demands. New industries are springing up and many find employment in them. As a rule the increased demand for labor caused by the establishment of these industries is not offset by the closing up of other industries. Certainly it is true that scientific investigation has created large demands for labor that could hardly find employment without these demands.

The welfare of a nation depends to a large extent upon the success of its industries. In his address as president of the British Association for the Advancement of Science given last summer Sir Norman Lockyer quotes Mr. Chamberlain thus: "I do not think it is necessary for me to say anything as to the urgency and necessity of scientific training. . . . It is not too much to say that the existence of this country, as the great commercial nation, depends upon it. . . . It depends very much upon what we are doing now, at the beginning of the twentieth century, whether at its end we shall continue to maintain our supremacy or even equality with our great commercial and manufacturing rivals." In another part of his address Sir Norman

Lockyer says: "Further, I am told that the sum of £24,000,000 is less than half the amount by which Germany is yearly enriched by having improved upon our chemical industries, owing to our lack of scientific training. Many other industries have been attacked in the same way since, but taking this one instance alone, if we had spent this money fifty years ago, when the Prince Consort first called attention to our backwardness, the nation would now be much richer than it is, and would have much less to fear from competition."

But enough on the purely material side. Let us turn to the intellectual results of scientific investigation. This part of our subject might be summed up in a few words. It is so obvious that the intellectual condition of mankind is a direct result of scientific investigation that one hesitates to make the statement. The mind of man can not carry him much in advance of his knowledge of the facts. Intellectual gains can be made only by discoveries, and discoveries can be made only by investigation. One generation differs from another in the way it looks at the world. A generation that thinks the earth is the center of the universe differs intellectually from one that has learned the true position of the earth in the solar system, and the general relations of the solar system to other similar systems that make up the universe. A generation that sees in every species of animal and plant evidence of a special creative act differs from one that has recognized the general truth of the conception of evolution. And so in every department of knowledge the great generalizations that have been reached through the persistent efforts of scientific investigators are the intellectual gains that have resulted. These great generalizations measure the intellectual wealth of mankind. They are the foundations of all profitable thought. While the generalizations of science belong to the world, not all the world takes advantage of its opportunities. Nation differs from nation intellectually as individual differs from individual. It is not, however, the possession of knowledge that makes the efficient individual and the efficient nation. It is well known that an individual may be very learned and at the same time very inefficient. The question is, what use does he make of his knowledge? When we speak of intellectual results of scientific investigation, we mean not only accumulated knowledge, but the way in which this knowledge is invested. A man who simply accumulates money and does not see to it that this money is carefully invested, is a miser, and no large results can come from his efforts. While, then, the intellectual state of a nation is measured partly by the extent to which it has taken possession of the generalizations that belong to the world, it is also measured by the extent to which the methods by which knowledge is accumulated have been brought into requisition and have become a part of the equipment of the people of that nation. The intellectual progress of a nation depends upon the

adoption of scientific methods in dealing with intellectual problems. The scientific method is applicable to all kinds of intellectual problems. We need it in every department of activity. I have sometimes wondered what the result would be if the scientific method could be employed in all the manifold problems connected with the managament of a government. Questions of tariff, of finance, of international relations would be dealt with much more satisfactorily than at present if the spirit of the scientific method were breathed into those who are called upon to deal with these questions. It is plain, I think, that the higher the intellectual state of a nation the better will it deal with all the problems that present themselves. As the intellectual state is a direct result of scientific investigation, it is clear that the nation that adopts the scientific method will in the end outrank both intellectually and industrially the nation that does not.

What are the ethical results of scientific investigation? No one can tell. There is one thought that in this connection I should like to impress upon you. The fundamental characteristic of the scientific method is honesty. In dealing with any question science asks no favors. The sole object is to learn the truth, and to be guided by the truth. Absolute accuracy, absolute fidelity, absolute honesty are the prime conditions of scientific progress. I believe that the constant use of the scientific method must in the end leave its impress upon him who uses it. The results will not be satisfactory in all cases, but the tendency will be in the right direction. A life spent in accordance with scientific teachings would be of a high order. It would practically conform to the teachings of the highest types of religion. The motives would be different, but so far as conduct is concerned the results would be practically identical. I need not enlarge upon this subject. Unfortunately, abstract truth and knowledge of facts and of the conclusions to be drawn from them do not at present furnish a sufficient basis for right living in the case of the great majority of mankind, and science can not now, and I do not believe it ever can, take the place of religion in some form. When the feeling that the two are antagonistic wears away, as it is wearing away, it will no doubt be seen that one supplements the other, in so far as they have to do with the conduct of man.

What are we doing in this country to encourage scientific investigation? Not until about a quarter of a century ago can it be said that it met with any encouragement. Since then there has been a great change. Up to that time research was sporadic. Soon after it became almost epidemic. The direct cause of the change was the establishing of courses in our universities for the training of investigators somewhat upon the lines followed in the German universities. In these courses the carrying out of an investigation plays an important part. This is

in fact, the culmination of the course. At first there were not many following these courses, but it was not long before there was a demand for the products. Those who could present evidence that they had followed such courses were generally given the preference. This was especially true in the case of appointments in the colleges, some colleges even going so far as to decline to appoint any one who had not taken the degree of doctor of philosophy, which is the badge of the course that involves investigation. As the demand for those who had received this training increased, the number of those seeking it increased at least in the same proportion. New unversities were established and old ones caught the spirit of the new movement until from one end of the country to the other centers of scientific activity are now found, and the amount of research work that is done is enormous compared with what was done twenty-five or thirty years ago. Many of those who get a taste of the work of investigation become fascinated by it and are anxious to devote their lives to it. At present, with the facilities for such work available, it seems probable that most of those who have a strong desire and the necessary industry and ability to follow it find their opportunity somewhere. There is little danger of our losing a genius or even one with fair talent. The world is on the lookout for them. The demand for those who can do good research work is greater than the supply. To be sure the material rewards are not as a rule as great as those that are likely to be won by the ablest members of some other professions and occupations, and as long as this condition of affairs continues to exist there will not be as many men of the highest intellectual order engaged in this work as we should like to see. On the other hand, when we consider the great progress that has been made during the last twenty-five years or so, we have every reason to take a cheerful view of the future. If as much progress should be made in the next quarter century, we shall, to say the least, be able to compete with the foremost nations of the world in scientific investigation. In my opinion this progress is largely dependent upon the development of our universities. Without the opportunities for training in the methods of scientific investigation there will be but few investigators. It is necessary to have a large number in order that the principle of selection may operate. In this line of work as in others, many are called, but few are chosen.

Another fact that is working advantageously to increase the amount of scientific research done in this country is the support given by the government in its different scientific bureaus. The Geological Survey, the Department of Agriculture, the Coast and Geodetic Survey, the National Bureau of Standards and other departments are carrying on a large amount of excellent scientific work, and thus helping most efficiently to spread the scientific spirit throughout the land.

Finally, two exceedingly interesting experiments in the way of encouraging scientific investigation are now attracting the attention of the world. I mean, of course, the Carnegie Institution, with its endowment of $10,000,000 and the Rockefeller Institute, devoted to investigations in the field of medicine, which will no doubt be adequately endowed. It is too early to express an opinion in regard to the influence of these great foundations upon the progress of scientific investigation. As both will make possible the carrying out of many investigations that would otherwise probably not be carried out, the chances of achieving valuable results will be increased. The danger is that those who are responsible for the management of the funds will be disappointed that the results are not at once of a striking character, and that they will be tempted to change the method of applying the money before those who are using it have had a fair chance. But we who are on the outside know little of the plans of those who are inside. All signs indicate that they are making an earnest effort to solve an exceedingly difficult problem, and all who have the opportunity should do everything in their power to aid them.

In the changes which have been brought about in the condition of science in this country since 1848, it is safe to say that this association has either directly or indirectly played a leading part. It is certain that for the labors of scientific men increased facilities and a wider usefulness have been procured.

COMRADES IN ZEAL.*

By DAVID STARR JORDAN,

PRESIDENT OF LELAND STANFORD JR. UNIVERSITY.

THE Society of Sigma Xi was founded in 1886 at Cornell University. Its godfather was Henry Shaler Williams, and its name, σπουδῶν ξυνώνητε, companions in zealous research, comrades in zeal, indicates as well as two words can, even in that wonderful language of the Greeks, the purpose of the society. It was intended to bind together scientific thought and action, the workers in pure science and those who dignify it by its application to human affairs.

The society has now its chapters in 16 American universities. Its members number upwards of 2,500, about 500 of them active, that is, still lingering about the university which is the center of the collective efforts of Sigma Xi, the rest scattered over the world in the various avocations appropriate to the zealous comradery.

The society of Sigma Xi stands for the glory of research, the joy of knowing, the uplift which comes from 'seeing things as they really are,' and the doing the thing that such seeing shows us ought to be done. Its essence is in Huxley's phrase the 'fanaticism for veracity,' the zeal for fair play, that would not have even the least of nature's records slurred over or wrongly interpreted. It stands at the same time for the zeal for action, for the strenuous use of the knowledge already acquired in the affairs of men. For pure science and applied science it finds place alike, for each has its roots in independent research, and in each the fanaticism for veracity is fundamental to the highest work. Its purpose is to excite this fanaticism for veracity, and zeal for action among the university students of America, and to foster it by means of the fellow-feeling among free spirits, 'Gemeingeist unter freien Geistern,' which was once declared to uphold scholarship in Germany.

For the Sigma Xi is a university organization dealing with university men, and not directly with any others. Moreover, the society is not the university itself. It is a small part of any one institution —a large part only when taken in the aggregate. It gives no material aids to scholarship. It builds no laboratories, establishes no libraries, endows no fellowships, offers no prizes, grants no honors worthy of the name. In its elections it picks out youth of promise, enlisting them as privates in its service. It undertakes to crown no achievement. It

* Address at the first annual banquet of the Honorary Society of Sigma Xi, St. Louis, December 31, 1903.

works through one channel only, that of comradery in research. We are Spudon Xynones—fellow pilgrims in a joyous land—full of glorious scenes, broad outlooks and repaying experiences. But the way we travel is beset with many difficulties both within and without. There are many temptations to turn aside from the main quest, from the large joys to the immediate successes, and the number of those who to the end remain Xynones is far less than the number who first strike out on the trail. These temptations are internal for the most part. The response to them depends on the man, not on anything outside of him. They are the intrinsic factors in his scientific evolution. But there are also extrinsic factors which undermine zeal and discourage enthusiasm. These extrinsic factors are sometimes potent, though relatively few, while the influence of the intrinsic factors decimates our band; wherefore we conclude that the individual in science is more than the environment. Men of research are born more often than made, but those well born may be spoiled or half-spoiled in the making. To prevent this, to keep the ranks firm, it is well for us to stand together, as comrades in zeal, and when necessary, as to-night, we may whistle bravely to keep up our courage.

And in standing together, it is well for men interested in one line of research not to look down on those whose taste or capacity favors some other. So long as it is real, research is the real thing, and one line may come as near the heart of things as another. Whence it is not good for the experimenter to look down on the systematist, the student of exact sciences on the mathematics of the imagination, the physicist on the psychologist, the chemist on the engineer, the engineer on the economist, the biologist who thinks in terms of chemistry only on the biologist who finds vital force a convenient temporary conception while searching for underlying causes, or any class on any other class, each being a loyal follower of the clue which has come into his hands. To be sure, not all is science which takes that name. 'Science falsely so called' is known to all of us as well as to the theologian. Of course, the name of science, even the name of research, is borrowed for purposes utterly at variance with science. Trade-marks which have a value are always imitated. With all that in the long run, there comes to be a science of non-science when even christian science and psychical research will ultimately find a place in the pigeon-holes of investigation.

In general, scientific research may be divided into four or five great classes.

Experiment.—The purpose of experiment is to test laws, to find out how things work. We arrange the conditions, nature does the rest, and our part of the process is to find out what the rest is. In the old days experiment was easy—to let fall an apple, to rub the hair of a cat, to bring a nail near a magnet. Nature would take advantage

of the situation and give us a hard answer to an easy question. We have not only to note what she does, but to find out why she does it, or rather why she doesn't do the reverse; for so perverse is nature that she never does any one thing unless she is cut off from doing all other possible things. It never rains when it could possibly do anything else; it is never clear when it could possibly rain. It has been shown that the crab runs sidewise, because such is the perverse nature of the crab, that if it could possibly run in any other way it would do so. The crab is a chip of the great block of Mother Nature. She is so perverse that she never does anything save when she has to. It is no easy thing to say why the limitations we find through experiment are inherent in the very nature of things.

And experimentation is no longer easy. All the obvious questions have been asked. All the obvious answers have been analyzed into infinite difficulties. It takes a master mind to devise a new problem. It takes almost infinite neatness and delicacy of touch to arrange the scenery, and infinite patience to wait for the result. To examine ten thousand minute eggs of a sea-urchin to see if perchance one has been fertilized in some impossible way, so as to eliminate all side conditions from an intricate problem—this requires enthusiasm and patience of a new order, a fanaticism for veracity not rewarded by the ringing of bells nor by scarlet sashes nor a coat with green palms. It can only be encouraged by the comradery of free-spirits, who value the fragment of truth which these methods bring, and who respect the man who gives his time and strength to know a little truth—to know it, not to guess it. Fanaticism for veracity—this is a good word, and those who heed it need all encouragement.

What we wish to encourage is not a specific achievement, but rather a habit of mind. To see clearly, to see deeply, to see with an understanding heart—this is the nature of research. It is not compilation, it is not publication, it is not the formation of curves, nor the giving of new names, nor the stacking up of columns of figures, though each or any of these may lie along the way as necessary accompaniments, as much a part of a piece of research as a walking-stick or a hat band is a part of a journey. 'Fanaticism for veracity' covers the whole matter, and as fanatics of a new order, F. F. V., with a new significance, we rally together under the sign of Sigma Xi.

Comrades in zeal for truth, we care enough for accuracy to sacrifice for it our money, our time, and even, if necessary, some of us give our lives for it. Enough of us have done so to show what the others of the brotherhood would do if placed under like circumstances or if subjected to like demands.

But experiment is not all of science. A large part of the work of scientific research must be simply descriptive, the attempt to record things in the world as they are—just as they are. It is dealing with

nature in a static way, the record of experiments of nature herself, so long in trying, that we do not recognize her movement at all. Wherefore descriptive science seems less exhilarating than experimental science. It has less movement to it; for nature does not seem to move, and we need not as we watch her; yet static knowledge lies at the foundation of most discoveries in dynamic nature. We must know the plants and animals of any given region and know them exactly before we can study migrations and movements, the origin of faunas, the distribution of forms. The movements in geologic time are best traced by the shells which the rocks carry with them, and these shells admit of no experiment, have no apparent dynamic significance. Descriptive anatomy precedes physiology and interprets it; embryology interprets anatomy, but to a like degree anatomy interprets embryology. Ecology, the study of life histories, interprets all these and is explained by them. According to Lubbock, the knowledge of the habits of animals, their reaction to stimuli, external and internal, is the final end of zoological science.

It has been a fashion of the *fin du siècle* sort, a fad of the last end of the last century, for workers in other lines to look down on systematic zoology and systematic botany. They would know the general structure and relations of animals and plants in a great large way, but were infinitely bored by the details, and especially by those of the larger forms, those which can not be sliced and imbedded in Canada balsam. This feeling is unworthy of large-minded men. As I said just now, it is not good form in science for one set of workers to look down on another. The varied details of systematic science embody the fanaticism for veracity of the men who have worked them out. It is, after all, the man who does the minute work who advances science. Anybody can devise new groupings of large lines of facts. The man who found out the least true detail about the heart of the lancelet, even the man who found a new kind of lancelet in the sands of the Bahamas, contributed more to science than the men who gave new names to the class of lancelets in their new schemes of vertebrate classification. As if Leptocardii were not good enough, we have these little creatures called Acrania, Pharyngobranchii, Cephalochorda or Cirrostomi. We all know that the lancelet is headless, that it has gill slits around the throat, a nerve cord where its head ought to be, and cirri about its mouth, but we knew that when they were Leptocardii or merely lancelets, and these new names merely cumber the books without adding at all to our knowledge.

Linnæus once said, with the fine sarcasm of the ancients: 'Tyro novit classes, magister fit species.' Any beginner can define classes of plants. It takes a master to work out the species. Any beginner can see things in the large; all the world does that; but only the master can get down to details. He can shut his eyes to all outside, and can

make from nature a faithful transcript. It has been said that all advance in knowledge is really quantitative. We must come down to micro-measurements if we are to see more deeply than others have seen, if we are to add to the store of human knowledge.

On the great chart made by the descriptive naturalist the experimenters locate their work. As well try to study geography without maps as to work at the great problems of geographic distribution, without correct faunal lists of species. To study wisely the origin of species, the evolution of forms without knowing species, many species, and knowing them as species, is impossible, as many naturalists have clearly shown by the method of awful example. To fill out the great chart of the descriptive chemists, experiments in chemistry are carried on, and in some degree the same condition holds for physics, astronomy and the other sciences. The word *science* has been defined as knowledge set in order. A large adjunct of research, even if it be not part of research itself, is the work of setting knowledge in order. Very often the man who brings clearness out of confusion has contributed more to science than the discoverer of the facts with which he deals. It takes a high order of mind to sift the evidence, to brush aside the cobwebs, to bring forth the truth. To do this well, one should have large experience with creative work. It was not the least of Darwin's merits that he was able to deal with the records of thousands of men, to bring out clearly what these records showed, though not one of the actual discoverers even dimly suspected the meaning of their work. At the same time Darwin was not once deceived by the errors of other men. Each record he accepted from some one else remains unimpeached to this day. To set knowledge in order requires a master in the value of evidence, and for this reason the authors of index, record, anzeiger and bibliography should be held in esteem in science. To do this work one must know how to do it, and to know how is to have had already a large experience in the kind of work which the index or bibliography is designed to help.

Setting in order the results of research may not demand as high an order of genius as is needed to push forward the line of advance, yet most great investigators have found relating their own work to the work of others a welcome as well as a necessary task. It is the duty of every investigator to enable his successors to start farther along than he was able to do. To enter into the work of others implies that our predecessors have smoothed the path and cleared the way to further advances. Whence the experimenter should not look down on the bibliographer or even the compiler, providing that these do their work with a master's mind and conscience. Good work in the poorest fields is better than bad work in the richest. The progress of science depends not so much on the field actually worked, not even on the method chosen, but rather on the brains, conscience and courage a man puts into his work.

Another line of work is that of invention, the application of the discoveries of science to human needs. It is the fashion to decry science of this sort as commercial, and to speak with scorn of the financial rewards which await those who are successful in its pursuit.

But I am glad that the Sigma Xi finds room for the creative engineer. In its last analysis the ultimate purpose of knowledge is the regulation of human conduct. The end of knowing is doing, and the justification of scientific research is that it makes life more comfortable, saner and richer. It is true that pure science must precede creation, but into some form of creative art all experimental science sooner or later finds its way. We may then welcome the engineer as an inseparable companion in the domain of science, comrade in zeal, diverging in method, but loyal to fanaticism to the truth he can touch and feel.

Highest of all lines of scientific work, most difficult of all, and withal most susceptible of degeneration, is the study of causes and relations. This work is closely connected with all other forms of research; for every fact observed points us to the consideration of its cause.

Each fact must be the resultant of some adequate force. 'The globe is transparent law, not a mass of facts.' So Emerson tells us. Law is the expression of the relation of cause and effect. Nothing would be as it is, could it by any possibility have been something else. Nothing is variable in the universe save the wayward human will, and that only because its stimuli and reactions are too finely balanced to be measured by our instruments of precision.

Each peculiarity of structure, each character or quality of individual or species, has a meaning or a cause. It is the work of the investigator to find this meaning as well as to record the fact. "One of the noblest lessons left to the world by Darwin," Frank Cramer says, "is this, which to him amounted to a profound, almost religious, conviction, that every fact in nature, no matter how insignificant, every stripe of color, every tint of flowers, the length of an orchid's nectary, unusual height in a plant, all the infinite variety of apparently insignificant things, is full of significance." For him it was an historical record, the revelation of a cause, the lurking place of a principle.

For this reason, every line of work leads back to a causal interpretation. Every fact clamors for it. This is the strongest impulse which urges the devotee of science, the comrade in zeal, and his only danger is that he respond to these calls prematurely. The ultimate end of scientific research is found in prophecy, not in proclamations of the mystic order, but in such mastery of the solid ground of the present that we can tread with firm step on the solid ground of the future, 'the action of existing causes.' This interprets all that has been; foretells all that is to be. The value of all facts is found in their relation to such interpretation and such prophecy. It is the function of prophecy, as Dr. Wilhelm Ostwald has shown, which distinguishes the

new civilization from the old, 'and the word which expresses this difference is science.' "The height of any civilization," says Dr. Ostwald, "may be directly measured by the thoughtfulness with which the prophets of civilization understand their calling and are able to predict this future. In the struggle for existence the man will be most efficient who can answer these questions: what will happen? and with what certainty, more accurately than his fellow men."

"If we ask," continues Dr. Ostwald: "What is the most general force which has been active in historical times within our knowledge, and is still active, we recognize that it is the *conquest of all intellectual fields by science.* If we imagine the most primitive conditions in the development of mankind, we see that there is no doubt that the individual and the race which is finally successful in the struggle for existence is the one that learns to see most clearly into the conditions of the future and thus learns to influence them. There are conditions in which the war of physical force seems to settle the question; but even here we see skill, that is, the intellectual or scientific factor, offset a large part of the brute strength, and this factor increases as development advances. The greatest leaders of men have been those who saw most clearly into the future.

"Thus every political and moral organization is dependent upon biographical conditions; and these fields are evidently those which are destined to be irresistibly conquered by science."

To us, as 'prophets of civilization,' to use again Dr. Ostwald's illuminating phrase, every line of scientific research has its danger—the danger of inadequacy. In causal interpretation, the impulse is toward superficiality, to premature proclamation of opinions issuing from the heart rather than sanctioned by the head, the tendency toward futile speculation, barren epistemology, or florid sentimentalism. While magister fit species, tyro novit classes, a beginner can frame great generalizations and a great many of them, which it would take a master of masters to define and sustain. 'A flaw in thought an inch long'—this is a Chinese proverb—'may be felt for a thousand miles.' It is the flaw in thought, the flaw in fundamental conception, which distinguishes the sage in science from the speculative philosopher. In this matter we are fortunately not without adequate models. The boldest speculator in biology was also the one of all his century most careful as to his facts. In the twenty-five years of building the hypothesis of the origin of variety in life, Darwin scrutinized each least fact as though it were the center of the whole system. From which it followed that there was no unsound material in the fabric he built. And for this attention to each detail, rather than for the greatness of his final conception, we place Darwin first among the naturalists of all time. Other men had thought of natural selection, had imagined the survival of the fittest, had shown the divergence of forms of life

under diverse environment. Only Darwin could show with the demonstration of ten thousand instances that this condition was naturally inevitable, that the origin of species was written in the very nature of things set in the creation of life.

As causal interpretation in weak hands degenerates into speculation, so are all other forms of research subject to deterioration. Experimenters are peculiarly subject to myopia, shortsightedness, narrowness, carelessness as to truth obtained in other ways, and indifference to the outlooks a broader horizon obtains. With all the intensive accuracy of the science of Germany, we have often to look to other countries, notably to England, for the broader view which sets each fact in place.

Systematic or descriptive work often finds its end in pedantry, the accumulation or the ostentation of meaningless knowledge, or in the forming of useless names and the gathering of pointless statistics. The work of setting in order often slides downward through easy stages of copying, compiling and dictionary work, work designed to 'hold the eel of science by the tail,' but which sometimes retains only the slime from that vivacious fish. Ecology too easily falls into sentimental personification of living organisms, not the study of Nature, but the cultivation of our own emotions regarding her. Inventive science degenerates into management of properties and science is lost in the search for salaries for holding down a job. For in engineering there is a subtle line, easily passed, which separates the comrade in zeal from the successful superintendent of a mine or foreman of a machine shop, just as in pure science there is a narrow line which distinguishes advance in knowledge from the simple keeping of what is already in our possession.

We must all rejoice in the steady increase of means for work in America, the multiplication of libraries, laboratories, museums, instruments of precision and facilities for publication, made ready to our hand. These will increase the output in science; they will improve its quality; but they will have little effect on the actual number of investigators.

I am forced to believe that investigators can not be made by opportunity only—merely made better. Not many who would have been investigators have been deterred by scanty means, by burden of work, by lack of encouragement. The impulse of the investigator, as his reward, must be within himself. His results may be incomplete, his product scanty, his outlook narrow, but he will not fail to bring forth after his own kind. A stalk of corn in stony soil may yield but little grain, but what there is will still be corn. You can not starve it down to oats nor feed it till it becomes a banana. I have no faith in the men who might have been productive investigators if they only had a

chance. The world is the opportunity of the man who can seize it. All the true naturalist demands is to be born into it.

In like fashion, splendid resources count for nothing till they fall into the right hands. The existence of a microscope or microtome is no guarantee that some one will use it. The presence of a collection is no sign that some one will study it. It requires courage and zeal to lay hold of anything, and these qualities do not always dwell in kings' houses. Generous facilities can not take the place of men, and the best working rooms in the world will not raise mediocrity into genius. Haeckel once said bitterly that the output of laboratories in biology was always in inverse ratio to the completeness of their appointments.

For there are always influences at work, extrinsic and intrinsic forces, as I said just now, which oppose the spirit of investigation. Among these I class all which tend to make investigation perfunctory and all those which crown achievement with worldly reward. I have known men in European museums to say deliberately: It is time to put out another paper. What is the easiest thing I can do? Meanwhile searching for the line of work which will yield the largest number of pages for the amount of energy put forth. Something of this sort results from the pressure of university publication committees. So many pages of original research demanded for each month in the calendar. Better not print at all than to make it a stated function. On the whole, I place the fellowship system as a discouragement to research. The real comrade in zealous learning is a man who can take care of himself. To get his own training where he can do it best, in his own way, at his own cost, is one of the best parts of his scientific training. The free lunch at the university tempts those who are hungry, the pedant, the place-seeker, the second-hand scholar—to the prejudice of the investigator. The kind of man who best passes examinations is not the original, the forceful, the creative scholar. He has something better than examinations to think about. It is not to the credit of the American university system that the number of doctors of philosophy—to borrow a suggestion from Dr. Jacques Loeb—each year corresponds almost exactly to the number of young men hired to study in the particular institution. So many fellowships, so many doctors of philosophy. Very few of these stall-fed scholars have the courage or the conscience to do independent work after the outside stimulus is withdrawn.

Within the walls of the academy the place of the investigator is not sure. Temptations assail him here from within and from without. One of the meanest is the impulse to acquire a reputation cheaply, to conduct his researches under the lime light, making great discoveries while the printer waits. Yet our newspapers are full of grave discussions of the outgivings of these lackeys of science. Almost equally cheap is the temptation to publication for publication's sake, to have

something in the market, something to serve at the show-down to show to the advantage of the writer or of his university.

On the other hand, the pressure of university duties often gradually extinguishes the investigator in developing the teacher. The college professor has many students to look after, many committee meetings to attend, many papers to read, many lectures to give, many whist parties to go through—many mouths to feed, while the apparatus rusts, the specimens gather mold or go to feed the *Dermestes,* while the half-begun manuscript is laid away for the season which never comes. Too often the young investigator, transplanted from the German hot-bed, with the easy success of the easy thesis, finds no adequate impulse to continue his work. Nobody cares for his conclusions, nothing depends on them. His place is secure and becomes more so from year to year, and at last instead of fanaticism for veracity, we find a mild form of approval of truth.

Besides all this there are many counterfeit presentments of investigation. Some years ago I had occasion to say:

"I am well aware that there is a cant of investigation, as of religion and all other good things. Germany, for example, is full of young men who set forth to investigate, not because they 'are called to explore truth,' but because research is the popular fad, and inroads into new fields the prerequisite to promotion. And so they burrow into every corner in science, philology, philosophy and history, and produce their petty results in as automatic a fashion as if they were so many excavating machines. Real investigators are born, not made, and this uninspired digging into old roots and 'Urquellen' bears the same relation to the work of the real investigators that the Latin verses of Rugby and Eton bear to Virgil and Horace. Nevertheless, it is true that no second-hand man was ever a great teacher. I very much doubt if any really great investigator was ever a poor teacher. How could he be? The very presence of Asa Gray was an inspiration to students of botany for years after he had left the class-room. Such a man leaves the stamp of his greatness on every student who comes within the range of his influence."

Besides all this, the work of research itself has its difficulties and its limitations. Too often fanaticism for veracity is subtly transformed into fanaticism for an idea—just plain fanaticism—the farthest removed from the open-mindedness which is the sole condition of knowing the proclaiming truth. To proclaim an error in good faith and then to discard it when the real truth appears, is a great strain on human nature. Hence research gives place to partisanship, and there are not many times when a man of science should be a partisan. When such times come, when we have the whole truth lined against all error, there is not much question as to the outcome of the struggle, and the investigator is not needed in the fight. He can afford to let

the battle go on to its natural end while he forges new arms for new struggles in new places. There was no need for Darwin to combat the attacks made on the Darwinian theory. It could take care of itself. There were better things for the master to look after. In fact all scientific controversies are essentially unscientific. It is a little more than a century since the great war of the Plutonists and Neptunists was on in geology. The battle was not fought out by the doughty combatants on either side, but by men outside the struggle who brought new truths unknown to the controversialist. Desmarest mapped the volcanoes of Auvergne, and his answer to the question as to the origin of deposits was simply, 'Go and see.' The rocks will tell you. And in London the answer of Sedgwick and Murchison was not different. Let us make a geological map of England; then the rocks will tell us where they came from and the conditions of their deposit.

Yet whatever the discouragements within or without, we have in America two splendid sources of encouragement in scientific research. Ours is a motor country with a democratic people. Every impulse is toward action. Each thought finds its end in doing something. And this makes for zeal in science. It makes for the saving in time. It makes for singleness of heart. For to engage in scientific research is really to do something. It is not talk. It is not meditation. It has an end in view and this end must be reached by activity. Science is positive, aggressive, dynamic. It does not spring from lethargy, and the lands of physical inactivity are lands of scientific ignorance. To be in the forefront of action is a pledge of ultimate leadership in science. This pledge America has given and this she has begun to redeem. It is already true that no other country in the world has done so much as our own in scientific investigation carried on for the benefit of the people and at the people's expense.

The spirit of democracy favors the advance of science. Democracy seems at first to level, because it tears down all artificial props. All men start alike, and all ideas must struggle alike for existence. The tradition of a thousand years to a democracy, is, to borrow Huxley's phrase, 'but as the hearsay of yesterday.' And this should be true of all tradition in the face of truth. A truth is valued for what it is —nothing more. In a democracy truth stands on its own feet, as a man ought to, and it may be assailed from any side. Tradition does not help it, and there is no weight in authority. Democracy at least brings each one to his own. It is not a leveler. It is the great unequalizer, the power which makes each man equal to his own fate, regardless of the fate of all other men. And as no two men deserve the same in life, fair play must end in final inequality.

In the field in which I have worked, that of systematic zoology, it is easy to notice the influence of political conditions on the individual point of view. The American worker applies his rules regardless of

whether they affect great men or small. He knows no tradition large enough to check the movement of science. Among the Scandinavians and the Dutch, in nations too small to obscure the democracy of learning, we find much the same feeling. In France, in Germany, even in England, the tradition of great names, the customs of great museums, largely outweigh the testimony of the things themselves. It has taken a long time to bring about in these countries the application of the simple and necessary law of priority in nomenclature. To this law all naturalists have assented in theory, but with the reserve of exceptions in favor of great men or the traditions of great museums. The willingness to adopt new views, to utilize new classifications, to see things in new lights, is, broadly speaking, in proportion to the spirit of democracy by which a worker is surrounded. A perfect democracy means a perfect perspective—each man, each idea, each theory standing for what it is, with all the 'covering of make-believe thrown off.' For the zealous search in which we meet as comrades is the worship of the greatest God known to religion, the God of the things as they are.

And here come the reasons why even the prophets of civilization should cultivate the virtue of modesty. The universe, of which we have explored a few points, is so gigantic in space, so monstrous in duration, that it baffles all our powers of collective thought to conceive of its existence. 'Time is as long as space is wide.' We can not picture the universe as limitless in space or in time, nor can we think of it as having bounds in distance or in duration. And with all its grandeur, it is so finely put together, so delicately adjusted, so eternally interdependent, that the smallest of all its parts is as large as the largest, that if another atom could be brought in from beyond the range of space and added to its infinite side, even if this were done only a moment after time should cease to be, the whole mass of eternity might be thrown from its bearings, its adjustment destroyed and the creation of æons of evolution flung back into primitive chaos. Or again, may be not this, but something else might happen, for likely enough matter is nothing substantial at all, but each molecule merely the vortex of a whirling current of force. Wherefore, bearing on our scientific shoulders the vastness of a universe whose elements are unknowable, unthinkable, 'solid and substantial, vast and unchanging,' we may well, to-night, as Thackeray once said on a similar occasion, say, 'We may well think small beer of ourselves and pass around the bottle.'

THE PREDECESSORS OF COPERNICUS.

By EDWARD S. HOLDEN, Sc.D., LL.D.,
LIBRARIAN OF THE U. S. MILITARY ACADEMY.

THE records of the earliest Greek astronomy are very meager. Pythagoras, in the sixth century B. C., held that the heavenly bodies, the earth included, were spheres. Pythagoras is supposed to have known that lunar phases were caused by illumination from the sun; and the curved line separating the bright and dark parts of the moon throughout the month would naturally suggest that it was not a flat disc but a globe. He imagined all the stars to be fixed to a crystal sphere which daily turned round the earth and produced their rising and setting. Each of the seven planets (sun, moon, Mercury, Venus, Mars, Jupiter, Saturn) was attached to a sphere of its own, and their turning made harmonious sound—the music of the spheres. The distances of the several spheres were assigned in accordance with certain laws of music that Pythagoras had himself discovered. The idea of a spherical earth is thus some twenty-five hundred years old.

Philolaus, a Phythagorean of the fifth century B. C., maintained that the earth and all the planets (including the sun) revolved about a central fire. The idea of a moving earth was, therefore, not unfamiliar after his time and Copernicus quotes the Phythagoreans as authorities in the first chapters of his book *De Revolutionibus Orbium Cœlestium* (1543). But the sun was not the central fire in their system, as it is in nature. "This world Pythagoras and his followers asserted to be one of the stars, and they also said that there was another opposite to it, similar to it; and they called that one Antichthona; and he said that both were in one sphere which revolved from east to west, and by this revolution the sun was circled round us; now he was seen, and now he was not seen. And he said that the fire was in the center of these, considering the fire to be a more noble body than the water and than the earth, and giving the noblest center" (Dante, *Convito,* iii., chap. v.). The Pythagoreans took the sun to be about three times the distance of the moon from the earth.

We know too little of the reasons that led Aristarchus of Samos, in the third century B. C., to hold that the sun was motionless at the center of the celestial sphere and that the earth revolved about him, rotating on her axis as she went. He taught also that the fixed stars are at rest, and measured the sun's apparent diameter, fixing it at half a degree. The little that remains of his writings gives the very highest idea of his originality and practical genius.

The views of Aristarchus on the system of the universe are reported by Archimedes. "The World," he says, "is by the greater part of astronomers called a sphere whose center is the center of the earth and whose radius is the distance from the earth to the sun. But Aristarchus of Samos, in quoting this opinion, refutes it. According to him, the world is very much greater; he supposes the sun to be immovable, as also are the stars, and he believes that the earth turns round the sun as a center, and that the magnitude of the sphere of the fixed stars, whose center is that of the sun, is such that the circumference of the circle described by the earth is in proportion to the distance of the fixed stars as the center of a circle is to its surface." Copernicus himself did not announce and describe his system with the magistral completeness and brevity of these few words. It is clear that we have here not only the view of Aristarchus, but also the opinion of Archimedes. We must assume that this announcement was unknown to Copernicus who reports the misty theories of the Pythagoreans, but makes no mention of Aristarchus in this connection.*

Plato (428–347 B. C.) taught that the earth was the center of celestial motions and that the planets and stars revolved about it on eight concentric spheres or circles. He plainly states that the moon shines by the sun's reflected light. Plato was not primarily an astronomer, and in fact held astronomy to be less dignified than the pure geometry that underlaid celestial motions, but his astronomical opinions were always of influence, especially in the orient where he held a high authority. He expressed and enforced the general idea that the heavenly bodies, being perfect in their essence, must necessarily revolve in circles, and with uniform, not variable, motion.

Eudoxus of Cnidus (409–356 B. C.) elaborated the ideas of Plato into a scientific system. By this time the simpler motions of the moon were well known, and to account for them he found three spheres to be necessary. One produced its daily motion of rising and setting, another its monthly motion from west to east, while the third had to do with its motions north and south of the ecliptic. The sun was likewise provided with three spheres, and each of the planets had four (since the planets sometimes appear to 'retrograde' from east to west, though their usual progress is from west to east). The system of Eudoxus thus required twenty-seven spheres; one for the fixed stars, twenty for the planets, six for the sun and moon. It is not probable that Eudoxus and his school regarded these spheres as material crystal shells, but rather as geometrical and abstract vehicles for the resolution of observed mechanical movements into intelligible parts. But the notion of material crystal spheres perpetually recurs in Greek astronomy after his day, and was universally held by the vulgar.

* Copernicus had access to certain large collections of books and the catalogues of these collections exist to-day. I have had them searched and the works of Archimedes are not there mentioned.

Consider, for an instant, what is involved in the theory of revolving material crystal shells. The stars are at an immense distance, all fixed to a crystal surface, which revolves once in twenty-four hours. The sun is situated on the surface of another shell, but it can not be in one fixed spot on the surface, for we see it rise and set at different points of our horizon at different times of the year. What kind of a crystal shell is it upon which the sun can glide so far and no farther? No wonder that certain medieval writers felt the necessity of imagining two shells for each luminary between which the motion took place with freedom, beyond which there was no passage. What sort of shells are those that correspond to the planets, each of which moves at various rates in varied directions—sometimes eastward, sometimes westward, sometimes north, sometimes south? The details of a scheme like this are literally unthinkable. It must be accepted, if at all, by faith—by a faith founded in phrases.

The ancient astronomers did not, in general, seek knowledge for its own sake. They were either concerned about some practical matter, as the length of the year, the prediction of the seasons and the like; or else sought acquaintance with some aspect of divine or partly divine matter, such as formed the planets and the stars. The science of the middle ages has been summarized in a sentence: 'It was all divination, clairvoyance, unsubjected to our modern exact formulas, seeking in an instant of vision to concentrate a thousand experiences' (Pater). A few of the ancients, Archimedes and Aristarchus, for example, had what we call the modern spirit. Roger Bacon was the first to formulate it. Newton may be taken as its first thorough-going representative, for even Kepler and Galileo were deeply tinged at times with the medieval color.

The *Meteorologica* and the *De Cœlo* of Aristotle (384–322 B. C.) were the text-books of the middle ages. The doctrine of material spheres was frankly adopted in these books and in the writings derived from them. The geometric scheme of Eudoxus was transformed into a clumsy mechanism, and its complexity was further increased by the addition of other spheres, so that fifty-six in all were necessary to explain celestial motions. "The glorious philosopher, to whom nature opened her secrets most freely, proved in the second chapter of his *De Cœlo,* that this world, the earth, is of itself stable and fixed to all eternity. . . . Let it be enough to know, upon his great authority, that this earth is fixed and does not revolve, and that it, with the sea, is the center of the heavens. These heavens revolve round this center continuously even as we see" (Dante, *Convito,* iii., chap. v.). Until we remember that mechanics was an unknown science to the ancients and in the middle ages, it is almost impossible to conceive how professors could teach, or students accept, a system like Aristotle's that was, in essence, unintelligible. While Cremonini was expounding the *De Cœlo*

in one lecture-room at the University of Padua in 1592, Galileo was teaching the Euclid's *Elements* in another. It is easier to comprehend how students flocked to listen when a few years later Galileo began his lectures upon astronomy, although by the conditions of his professorship he was only permitted to expound the astronomy of Sacro Bosco.

Aristotle taught that the earth was spherical and gave reasons, good and bad, for his belief. The distance of the sun was fixed by a most ingenious method invented by Aristarchus of Samos (270 B. C.) who concluded that the sun was about 19 times more distant than the moon (it is, in fact, 390 times more distant). Hipparchus determined the moon's distance for himself* and took the sun to be 19 times more distant. He did not leave the earth in the central point of the sun's orbit, but shifted that center towards the sixth degree of *Gemini* by one twenty-fourth of the radius so as to account for observed inequalities in the annual motion. Ptolemy adopted this result without question, and it was accepted by astronomers for twelve centuries. It was not until the time of Kepler that it was proved that the sun must be at least fifty times as far away as the moon. This was one of the consequences of Tycho's accurate observations.

The Chaldeans and Egyptians held the earth to be a flat disc canopied by the sky—the firmament—and this was the view of the Hebrews. A distinctly Christian theory of the figure of the earth and heavens, drawn from scripture, was formulated by the Egyptian monk and traveler Cosmas Indicopleustes. According to this theory, the earth was a flat parallelogram surrounded by the four seas. "We say, therefore, with Isaiah, that the heaven embracing the universe is a vault; with Job, that it is joined to the earth; and with Moses, that the length of the earth is greater than its breadth." This explanation of appearances was very generally accepted as orthodox, and was held by the common people long after the learned had been convinced of the earth's sphericity by the arguments of Ptolemy and Aristotle. Isidore of Seville in the seventh century, and the Venerable Bede in the eighth, declared for the opinion of Aristotle; Dante in the thirteenth century supported it, and Columbus proved it in the fifteenth. In the sixteenth, Magellan's voyage of circumnavigation settled the vexed question once and for all.

There is in the library of the University of Cambridge, so Dr. Whewell reports, a French poem of the time of Edward the Second (1307–27) illustrated with drawings that show men standing upright on all parts of a spherical earth. By way of illustrating the tendency

* He fixed the greatest distance of the moon at 78, the least at 67, semi-diameters of the earth. The mean distance is, in fact, 60. The distance of the sun, according to Hipparchus, was 1,300 semi-diameters. It is really about 23,000.

of heavy bodies towards the earth's center other men are dropping balls into holes bored entirely through the globe and these balls are falling to the earth's midmost point—

That point to which from every part is dragged all heavy substance,

as Virgil explains to Dante in the thirty-fourth canto of the *Inferno*. The cosmogony of Dante in the *Divina Commedia* was accepted for centuries by Roman Catholics, as Milton's in the *Paradise Lost* has been adopted by protestants. For Dante the globe of the earth was the center of the world. It was surrounded by nine transparent spheres moved by angels. There was a crystal sphere for the moon, and others for Mercury, Venus, the sun, Mars, Jupiter, Saturn and the fixed stars, and beyond them the *Primum Mobile*—nine in all. Beyond the outer sphere was the *Empyrean*—here God sate. Below the earth is hell and here its god—Lucifer—reigned over bad angels. All the discord in the world came from them, even its storms, hail and lightning. The spheres of Eudoxus served as a base to Dante's system, which was adapted, with a poet's license, to a poet's use.*

In the *De Cœlo*, Aristotle lays down certain fundamental principles: The things of which the world is made are all solid bodies, and all have, therefore, three dimensions. The simple elements of nature must also have simple motions. So, indeed, fire and air have their natural motions upwards, water and earth, downwards, both in straight lines. But besides these motions there is also a circular motion, not natural to these elements, although it is a much more complete motion than the rectilinear. For the circle is, in itself, a complete line, which a straight line is not: There must, therefore, be certain things to which complete circular motion is natural: It follows that there must be a certain sort of bodies very different from the four elementary bodies, bodies that are more godlike, that must therefore stand above them: This finer essence was later named by the commentators 'Quinta Essentia'—our quintessence. The heavenly bodies are formed of this; they are spheres endowed with life and activity.

The question of the revolution of the earth in an orbit round the sun is discussed by Aristotle, and he rejects the idea for the reason that such a motion would necessarily produce a corresponding alteration in the place of each and every fixed star. The objection was perfectly valid. If the stars were only a little farther from us than Saturn, as Aristotle believed, a motion of the earth in an orbit would cause each star to move in an apparent parallactic orbit, a miniature copy of that of the earth. No such alteration of place was observable. Hence, said he, the earth did not move. Even the nearest stars are,

* The upper regions of Paradise contained the narrow-minded monks of the middle age as well as the great saints. The wisest and most virtuous heathens, like Virgil, were in *Limbo*—which, it has been remarked, contained the 'best society.' Outcasts from all religions, and sinners of all sorts, were in Hell.

we now know, twenty thousand times as far from us as Saturn, and it is this fact—which was not finally established till 1837—that explains why the miniature apparent orbits of the stars were not seen by the Greeks or by their successors. They were too minute to be discoverable.

All the important writings of Hipparchus, who lived in the second century B. C., are lost, and the doctrines of this 'most truth-loving and labor-loving man' are known to us only through Ptolemy, his expositor and ardent admirer. Hipparchus was an indefatigable observer, a mathematician of tact and insight, an astronomer of original and profound genius. By his own observations, made at Rhodes (188–127 B. C.), he fixed the positions (the celestial longitudes and latitudes) of the principal fixed stars. Comparing their present places with their past positions as determined by Timocharis and Aristillus, he discovered that backward motion of the equinoctial points which causes the epoch of the sun's passage through the equinox to recur earlier and earlier each year—the precession of the equinoxes—and fixed its probable annual amount. Comparing his own determinations of the date of the vernal equinoctial passage of the sun with those of Aristarchus, he determined the length of the year with accuracy.* It is by systematic comparisons of the sort that many of his discoveries were made.

It is very noteworthy that he gives not only his results, but likewise an estimate of their probable errors. His observations of the time of the sun's arriving at a solstice might be erroneous, he says, by about three fourths of a day; at an equinox by about one fourth. Comparisons made in this systematic fashion, and estimates of error of this sort, we are apt to think of as 'modern.' Certainly they are not characteristic of observational astronomy till the eighteenth century, two thousand years after Hipparchus showed the way. Some of his most important researches related to measures of time. What was the length of the year? Were all years of the same length? His observations showed him no difference between one year and another. It is interesting to note how he formulates his conclusions. He does not say that all years are, without doubt, of one and the same length; he asserts simply that the differences, if any, must be very small, so small that his observations are not delicate enough to detect them.

In the year 134 B. C. a new star suddenly appeared in *Scorpio,* and Hipparchus began the formation of a catalogue of stars visible to him. With such a conspectus of the present state of the sky no new appearances could subsequently occur without detection. His catalogue gave the position and magnitude (brightness) of 1,080 stars for the epoch 128 B. C., and arranged them in the constellation figures that have

* Hipparchus fixed the length of the tropical year at 365 days 5 hours 55 minutes. Its true length is 365 days 5 hours 48 minutes 45.51 seconds (1900).

come down to us only slightly changed.* Hipparchus' catalogue stood unique for a thousand years.

An instance of his practical tact as an observer may be quoted. If a straight ruler be held up against the starry sky there will, now and again, be instances where its edge passes through three stars at the same time. Many such cases are recorded by Hipparchus. No one of the three stars can change its situation without detection. A simple observation of the same sort at any subsequent time will at once exhibit any change that may have taken place in the interval between the two observations.

The work of Hipparchus as a theoretical astronomer is as remarkable as his observing skill. The positions of the heavenly bodies are calculated by solving triangles, both plane and spherical. The doctrine of such solutions—trigonometry—was perhaps invented by him; at all events it was greatly developed and improved. Observations give the celestial longitudes and latitudes of planets at the instant of observation. Their positions at past epochs, a month or a year ago, are given by preceding observations of the same sort. Where will Jupiter or Saturn be found in the future—a month or a year hence? It is necessary to invent a geometry of planetary motion that will account for all past and future motions; and this problem was elaborately developed by Hipparchus. We must recollect that his vast activity was exercised under conditions of the most discouraging kind. His best instruments were but rude; all sightings were made with the eye unaided by telescopes; he had only clepsydras (sand or water-clocks) to measure intervals of time; the Greek system of arithmetic in which his calculations were made was cumbrous in the extreme. What he accomplished is little less than astounding.

From his theory of Epicycles Hipparchus was able to construct his tables of the sun and moon. The tables gave the particulars of the motion of these bodies and enabled predictions to be made of coming solar and lunar eclipses. It was sufficient for the purposes of the time to assert that an eclipse would occur on a certain day, about a certain hour of the morning or afternoon, and the tables were adequate to such predictions. His theory was sufficient; it fulfilled all the tests applied to it. The motion of the moon was more complex than that of the sun, but it, too, was reduced to a sufficient order and important discoveries made. The elements of the motions of these bodies were not derived, as we to-day derive them, from continuous observations, but rather from observations made at certain critical times. For the sun the observations were made at the equinoxes and solstices. Six eclipses of the moon sufficed to give him the elements of the lunar orbit and the rate at which they were changing.

* Our constellation figures are those designed by Albrecht Dürer on the star maps of Stoeffler and Heinfogel from the descriptions of Ptolemy.

His theory of the planets was not so complete, for there was no sufficient body of ancient observations to be compared with those which he himself accumulated with so much diligence. Considering the data at his disposition and the use made of them, the work of Hipparchus is of the first order. Astronomers of all ages are agreed that he was 'one of the most extraordinary men of antiquity; the very greatest in the sciences that require a combination of observation with geometry' (Delambre).

His expositor, Ptolemy of Alexandria, was primarily a geometer and made few original observations. The *Almagest* is, in essence, a restatement of the theories of Hipparchus with additions, not all of which are improvements. It begins by laying down certain postulates: The earth is spherical and a mere point in respect of the heavens; its circumference is 180,000 *stadia;* the heavens are likewise spherical and revolve about the earth, which is in the center and has no motion. So far he is in agreement with Aristotle. Where he differs, astronomers who succeeded him followed the *Almagest* while philosophers were more apt to take Aristotle as authority.

Ptolemy's theory of the moon's motion led him to important discoveries, which need not be described here. It is mentioned because it also contained a contradiction of the precise sort that is best suited to lead to further discoveries, and because this contradiction was passed over and entirely neglected by him and by his successors for centuries. His theory gave the position of the moon with satisfactory accuracy. It was, in so far, presumably true. It assumed that at times the moon was twice as far from the earth as at others. If this were true the moon's apparent diameter should sometimes have been twice as great as at other times. But no such variation was observed. The necessary conclusion: Hence the theory can not possibly be true—was not drawn by Ptolemy. The instance is significant; it marks a radical difference between the modern attitude and that of the ancients in matters of physical science. Ptolemy and his successors really held two antagonistic theories of the moon's motion and distance at the same time. Each theory satisfied the conditions of part of the problem. They did not seek for a unique theory. This was not done until the time of Kepler, whose whole life was spent in searching for the physical causes of observed phenomena, and who was not content with mere analytic devices by which the phenomena could be predicted. He sought for these, but he looked deeper and further.

All but a few of the greatest of the ancients regarded a physical problem in the light of a riddle to which an answer was required. Any plausible answer would do. The fixed belief that there was one answer and could be only one did not arise till quite modern times. Modern science is a search for such unique solutions. Most of ancient science was a search for an hypothesis to account for a set of observed facts.

A page from Ptolemy's note-book may be transcribed. He was seeking the position of the bright star *Regulus:* "In the second year of Antoninus, the ninth day of Pharmauthi, the sun being near setting, the last division of *Taurus* being on the meridian (that is 5½ equinoctial hours after noon) the moon was in three degrees of *Pisces* by her distance from the sun (which was 92° 8′); and half an hour after, the sun having set, and the quarter of *Gemini* on the meridian, *Regulus* appeared, by the other circle of the astrolabe, 57½ degrees to the eastward of the moon in longitude." The position of the sun was known from the day of the year by the solar tables; the moon, at 5½ hours, was 92° 8′ east of the sun; the moon's motion in half an hour was also known from the tables, and hence her position at 6 hours was determined; *Regulus* was at that time 57½ degrees east of the moon, and its place was thus fixed with respect to the sun. A modern note-book would give the year and day, and would record that *Regulus* crossed the meridian at a certain hour, minute, second and decimal of a second by the clock. The correction of the clock would be given as so many seconds and hundredths of a second. The sum of the clock-time and the correction is the position of the star. In Ptolemy's case it was known to half a degree (two minutes of time). A modern observation gives it with an error not above one tenth of a second; that is with an accuracy about 1,200 times greater.

Ptolemy's *Almagest* is, in essence, 'modern' in respect of the fact that its theories are designed to give quantitative results and are presented as general bases for special calculations. With a certain set of observations as data the desired results could be worked out in numbers. Tables for calculating future positions of the planets were also given and in Ptolemy's time the actual positions were fairly well represented by the predictions. As time went on, more accurate observations with better instruments, were made. The observed places of the planets did not agree with the predictions. The ingenuity of his disciples in the middle ages was taxed to improve the theory, and the tables of Ptolemy were supplanted in turn by the Hakemite tables of Ibn Yunus (about A. D. 1000), the Toledan tables of Arzachel (1080), the Alphonsine tables of Alphonso the Wise (1252) and others. Finally, in the first half of the sixteenth century it became evident that Ptolemy's theory was itself gravely at fault. It was the fortune of Copernicus to open a new way to scientific thought—to lay down a new theory of the world.

The details of the long history thus sketched out are only interesting to astronomers.* We are here concerned with the main outlines alone.

* They are given in clear form in various encyclopedias and other books of reference. Perhaps Berry's *Short History of Astronomy* (1899) will best serve the purpose of the general reader. Gyldén's *Die Grundlehren der Astronomie* (1877) develops the mathematical bases of ancient astronomy in an elementary form. Delambre's *Histoire de l'Astronomie* is still the best general history.

The Arabian school of astronomers added nothing to the theory of Ptolemy. They transmitted the text of the *Almagest* to the west accompanied by intelligent comment and almost without criticism except in the cases of Alpetragius and Geber. The Arab observations were very numerous, and resulted in fixing new and much more accurate values of the constant of precession, the length of the year, the obliquity of the ecliptic, the eccentricity of the sun's orbit and the motion of its apogee. Their arithmetic was the clumsy sexagesimal arithmetic of the Greeks, until in the eleventh century the Hindu decimal system began to make its way in Egypt, Spain and Europe. Geometry is not indebted to the Arabs for any marked advances. On the other hand, trigonometry was greatly improved.

As observers the astronomers of the Arab school had great merit. They grasped the need for continuous observations, whereas the Greeks in general had contented themselves with making observations at certain critical times only—at the solstices and equinoxes, for instance. The Arabs were the first to assign the exact time at which any phenomenon occurred—a fundamental datum. They measured the altitude of the sun at the beginning and ending of solar eclipses, for example, in order that the time might be known. The calculation of a spherical triangle enabled the instants of beginning and ending to be accurately assigned. The Greeks never employed this device and the times of phenomena recorded by them are seldom known with any accuracy. Indeed Ptolemy has no formula by which to calculate the time when the sun's altitude is given, and it is noteworthy that the Arab device was not known in Europe until 1457, when Purbach used it for the first time. Yet it was employed at Bagdad at the solar eclipse of A. D. 829, six hundred years earlier. Even the times of phenomena recorded by Tycho Brahe in 1600 are seldom known so close as a quarter of an hour. Short intervals of time were measured by the Arabs by counting the beats of pendulums.

A few of the greatest Arabians are named in what follows. Albategnius was an Arab prince of Syria who flourished at the end of the ninth century of our era. His observations were made at Aracte (Rachah) in Mesopotamia and at Antioch, between the years 878 and 918. After studying the *Syntaxis* of Ptolemy he set himself to correct the errors of its catalogue of stars by observations of his own, made with apparatus fashioned after Ptolemy's descriptions. It appears that some of his instruments could be read to single minutes (1′) and were divided possibly to 2′ (or it may be to 6′). He detected the change of position of the sun's apogee, determined the obliquity of the ecliptic, the length of the year, the precession-constant (54″), observed and calculated solar and lunar eclipses and computed new tables of the planetary motions, although he did not seek to improve Ptolemy's planetary theory. He was original and inventive as an

observer; a sound mathematician; an expert and careful computer; and he introduced marked improvements in the methods of calculation. He holds the very first rank in the Arabian school. In his trigonometry he substituted sines for chords; reduced the calculation of spherical right triangles to four cases; and possessed a general rule for the solution of oblique spherical triangles in the cases (I.) given *a, b, c,* required *A*; (II.) given *a, b, C,* required *c*; was acquainted with the doctrine of tangents and cotangents, though he made no useful application of it; and seems to have known something of secants and cosecants. To understand his exact merits as an observer, it would be necessary to go into details that have no place here.

Ibn Yunus, the scion of a noble family, was the astronomer-royal of the Fatimite Caliphs of Cairo, where he constructed the Hakemite tables, in 1008, from his own observations. Comparing his own observations with those determined by Hipparchus or Ptolemy, he obtained accurate values of the changes that had supervened. They were accurate for two reasons: In the first place, the modern observation was very near to the truth; and in the second, the annual change was better determined the greater the interval of elapsed years. Albategnius and Ibn Yunus were 800 years after Ptolemy, while Ptolemy was but 263 years after Hipparchus, and Hipparchus but two centuries after Timocharis. The divisors increased with the lapse of time.*

"At Nishapur lived and died (early in the twelfth century) Omar Khayyam busied in winning knowledge of every kind, and especially in astronomy, wherein he attained to high preeminence. When Malik Shah determined to reform the calendar, Omar was one of the eight learned men required to do it; the result was the Jalili era, 'a computation of time,' says Gibbon, 'which surpassess the Julian and approaches the accuracy of the Gregorian style.' He is also the author of astronomical tables, and of a treatise on algebra" (Fitzgerald).

It is interesting to note that the Bagdad astronomers observed an eclipse of the sun by its reflection in water. The obliquity of the ecliptic for the year 1000 Ibn Yunus found to be 23° 33′ (the true value is 23° 34′ 16″). The latitude of Cairo he determined to be

* It may be remarked, in passing, that the foregoing explains how it is that Copernicus and Kepler had such accurate values of the periods of revolution of the different planets. Hipparchus noted, for example, that Mars was in conjunction with a certain star—Sirius for instance, on a certain day. Tycho, 1700 years later, observed that Mars was again in conjunction with Sirius on a certain day, at a certain hour. In the seventeen centuries that had elapsed, Mars had made about 860 revolutions. The interval of time between the two epochs, divided by the number of revolutions, gave the time of revolution with great exactness. On the other hand, the distance of Mars from the sun was only roughly known, even to Kepler. Of the dimensions of the planets nothing was known until their apparent angular diameters had been measured with the telescope. Anaxagoras held that the sun was about the same size as the Peloponesus.

30° (the true value is 30° 2′). Like all the Arabs he adopted the theories of the *Almagest* without change;* but his observations were materially better than Ptolemy's and his numerical results were, consequently, much more accurate. What is said of Ibn Yunus is, in general, true of the whole school of Arab and Moorish astronomers.

Ibn Yunus was acquainted with the Indian numerals 1, 2, 3, 4, 5, 6, 7, 8, 9, and used them occasionally in place of the clumsy Greek system, and he also introduced tangents and secants into trigonometry, as well as auxiliary angles (which latter were not used in Europe till the eighteenth century), but he continued to calculate triangles by formulæ involving sines only. Abul-Wafa of Bagdad (940–948) gave the formulæ relating to tangents and cotangents, and also to secants and cosecants, and even calculated tables of tangents; though he also stopped short of useful applications that were well within his reach. The science of trigonometry was, however, built up by Arabs, and the way was prepared for Vieta, who is the founder of the accepted doctrine. Abul-Wafa is the discoverer of the third inequality of the moon—the variation. Observing at a time when the first and second inequalities (discovered by Hipparchus and Ptolemy) had no effect, he noticed that the moon was a degree and a quarter from her calculated place. "Hence," he says, "I perceived that this inequality exists independently of the two first." This discovery remained unknown in Europe for six centuries until Tycho Brahe independently came to the same result.

Alhazen was an Arabian mathematician and astronomer of the eleventh century who is noteworthy for his treatment of physical problems, especially that of refraction. Ptolemy had experimented on the refraction of glass and of water and had made out the law that the angle of refraction is a fixed submultiple of the angle of incidence ($r = 1/m \cdot i$). This was denied by Alhazen, but the true law was not discovered till the time of Willebrod Snell in 1621, who found the relation $\sin r = 1/m \cdot \sin i$, where m has a different value for each different substance. Alhazen's 'Optics' treats of the anatomy of the eye, and of vision, and has several propositions relating to the physiology of seeing, and it remained the standard work until the time of Roger Bacon and Vitello (thirteenth century).

The astronomical instruments of the Arabs were greatly superior to those of the Greeks. The caliphs of Bagdad and of Cairo founded observatories and supplied them generously. The grandson of Jhenghiz-Khan maintained a splendid establishment of the sort at Meraga on

* It is to be noted, however, that the theories of Ptolemy, as understood by the Arabs, made some of the crystal spheres of the planets clash; and that Ptolemy's place for Mercury was consequently changed arbitrarily to allow room for its motion! This is not a change of *theory;* but it illustrates how slavishly the doctrine of spheres was followed by some of its votaries.

the northwest frontier of Persia under Nasr-ed-Din as chief astronomer. Here the Ilkhanic tables were prepared. Ulugh-Beg, prince of Samarkand, a grandson of Tamerlane, founded a great observatory in 1420, on the hill of Kolik, where a hundred observers and calculators were employed. Albategnius, another Arab prince, possessed admirable instruments, as we have seen. Astronomy was in favor with princes and caliphs, and flourished accordingly. We have seen that some of the instruments of Albategnius read to one minute of arc (1′) and were very likely divided to 2′. The observatory of Nisapur, in Khorassan, had in A. D. 851 a huge *armilla* reading to 1′. In 992 Al Chogandi set up at Bagdad a sextant of sixty feet radius. In 1260 the observatory of Meraga possessed, among many other instruments, a mural quadrant of twelve feet radius. Ulugh-Beg had a quadrant (perhaps a species of sun-dial) that had a radius of 180 feet. Colossal instruments of the sort permitted accurate readings of angles because the space corresponding to an arc of one minute was correspondingly large. Until the invention of the telescope accuracy was only to be attained by the use of large circles, and the Arabian school anticipated Tycho Brahe in the use of such instruments by several centuries. Some of the Arabian observers employed free-swinging pendulums to measure short intervals of time; and the science of gnomonics—the theory of sun-dialing—was extensively developed by them.

This is the place to describe the system by which Ptolemy explained the world. It will be sufficient to explain the two main problems that any system of astronomy was bound to consider, and to leave details to one side. These two chief problems were: (1) How to account for the rising and setting of the sun, moon, stars and planets —how to explain the general diurnal motion of all celestial bodies; (2) how to explain the motions of the planets among the stars. These motions are, in general, towards the east—but are varied by occasional westward motions, and interrupted by periods of no motion at the 'stations.' As we have seen, Ptolemy declared the earth to be a sphere fixed in the center of the heavens. The sphere of the fixed stars was at an immense distance, so that the earth was a mere point in respect of the distance of the stars and the stars revolved about the earth. All the observed phenomena of the rising and setting of the stars are satisfactorily explained in this way. Ptolemy perfectly understood that they could also be explained by the hypothesis of a rotating earth, but he concluded that it was easier to attribute motion to bodies like the stars which seem to be of the nature of fire, than to the solid earth. The sun, moon and planets share in the diurnal motion of the stars. It will be seen that no mechanical conception of the diurnal motion is attainable in this way without the assumption of crystal spheres. Ptolemy sought an analytic device by which

calculations of phenomena could be made, not a physical explanation based on mechanical laws.

The problems relating to the motions of the heavenly bodies are more complex and must be considered somewhat in detail. It is necessary to describe the observed phenomena for each body separately, and to adopt a system which will explain every phenomenon and appearance in turn.

The Moon.—The facts of observation, familiar to us all, are that the new moon sets in the west about sunset, and that on every succeeding night the moon sets at a later hour. It, therefore, moves to the east among the stars from night to night, which can readily be verified by observation. If the moon is near the stars of *Orion* on one night, it will be found many degrees to the east of them on the night following. It sets later and later every night throughout the month. If it is in the same longitude as the stars of *Orion* on any one day, it will be again in that longitude about a month (27 days) later (more exactly, $27^d\ 7^h\ 43^m\ 11^s.5$). It has moved through the whole circuit of the heavens, 360°, in 27 days. Ptolemy explained the phenomena, as we explain them to-day, by asserting that the moon revolves in an orbit, about the earth as a center, making a complete revolution among the stars (from one star back to the same star again) in 27 days. Its motion among the stars is always forward—always from west to east.

The Sun.—The observed phenomena with regard to the sun are of the same nature. If the sun rises at the same time as the bright star *Sirius* on a particular day of the year, on the next day it will rise later than *Sirius*. It has, therefore, moved a certain distance (about one degree) eastwardly during that day. On the next following day it will have moved about two degrees east of *Sirius* and will rise correspondingly later; and so on for each succeeding day. After 180 days (six months) the sun will have moved about 180 degrees to the east of *Sirius*. *Sirius* will be visible on the meridian at midnight, (when the sun is 180° away from the meridian). At the end of 365 days (more exactly, 365.2564 days) the sun will have moved eastward through 360° and will again rise at the same moment as *Sirius*. The sun, then, appears to move eastwardly among the stars (from one star back to the same star again) once in 365¼ days. At different times of the year it is among different groups of stars, and it is for this reason, therefore, that we see different groups of stars at different seasons of the year. *Orion* is visible in the winter skies, *Scorpio* in the summer, because *Orion* and *Scorpio* are 180 degrees apart in longitude. Ptolemy's explanation of all these phenomena is that the sun moves about the earth in a circular orbit at such a rate as to make a complete revolution in 365¼ days. The explanation of Copernicus is that the earth revolves about the sun in the same period.

It is to be noted that either of these explanations will completely account for all the observed phenomena.

New moon occurs when the earth, moon and sun are in a straight line. At sunset the new moon is seen in the west. After 27 days the moon has made one circuit among the stars, moving from west to east. But in those 27 days the sun has likewise moved eastwardly, about 27 degrees. The moon, then, has to make one circuit and a little more in order to be again in the line joining the earth and sun, in order to be again 'new.' The time from one new moon to the next—the lunar month—is about 29½ days (more exactly 29d 12h 55m 2s.9) for this reason. Just as there is a difference between the moon's sidereal and synodic period, so there is a corresponding difference between the sidereal and tropical year, because the equinoctial points are in motion relatively to the stars.

The Superior Planets.—In the system of Ptolemy, Mars, Jupiter and Saturn were supposed to be further from the earth than the sun—to be above it—and they were, therefore, called superior planets; while Mercury and Venus were called inferior planets. The facts of observations for one of the superior planets, for Mars, for example, are as follows. If on any day Mars rises at the same time as *Sirius,* on the next day it will rise a little later, and so on. The planet, therefore, moves eastwardly among the stars. It continues its motion so that at the end of 687 days (1.88 years) the planet again rises at the same time as *Sirius.* It has therefore made a complete circuit of the sky (from one star back to the same star again) in a little less than two years. Its orbit was supposed by Ptolemy to be a circle (the deferent) about the earth like the sun's orbit. In like manner Jupiter makes a revolution in 4,332 days (11.86 years), and Saturn in 10,759 days (29.46 years). Such are the general motions of the three superior planets; but there are irregularities in their motions that must be accounted for.

For example, the actual motion of the planet Jupiter among the stars for the year 1897 is as follows: Beginning on October 28, 1897, the planet's motion is eastwards until January 22, 1898; here it turns and moves westwards until May 28; here, again, it turns and moves eastwards and its direct motion continues for the rest of its period of nearly twelve years. Ptolemy accounted for the irregularities of motion just described by supposing that Jupiter revolved in a small circular orbit—the epicycle—once in 365 days, while, at the same time, the center of the epicycle moved along the circumference of the deferent circle, making a complete revolution in about twelve years.

As time elapses the center of Jupiter's epicycle will move onwards on the deferent while Jupiter will move onwards in its epicycle. The combination of these two motions will produce a direct motion of the planet. After Jupiter has moved through a quarter of a circumference on its epicycle the planet will appear to the observer on the earth to move in a retrograde direction, because it will move to the right or left on its epicycle faster than the center of the

epicycle moves to the left or right. Hence the planet will appear to an observer to be moving in a retrograde direction—east to west. The epicyclic motion combined with the motion of the epicycle forwards along the deferent will produce first the retrograde and (in the last quadrant of the epicycle) again the direct motion of the planet in the sky. By taking the diameter of the epicycle of an appropriate size all the circumstances of the apparent motion of Jupiter can be represented. The explanation given by Ptolemy is complete and satisfactory. The general motion of the planet around the sky in twelve years is explained by the motion along the deferent. Its retrogradations and stations are explained by the combination of its epicyclic motion with its general motion. A like explanation serves for the other superior planets, Mars and Saturn.

The Inferior Planets.—The inferior planets, Mercury and Venus, appear sometimes east of the sun, sometimes west of it, but are never very far distant from the sun. We see them at sunset and sunrise as the morning and evening stars, Hesperus and Phosphorus, always in the sun's vicinity. Ptolemy explained their apparent motions completely and accurately by supposing that the centers of their epicycles revolved round the circumferences of their deferents in 365¼ days; and that Mercury revolved round the circumference of its epicycle in 88 days, Venus round the circumference of its epicycle in 225 days. The sizes of the epicycles were chosen to correspond to the amount of each planet's greatest elongation from the sun. In the foregoing summary explanation only the main phenomena are described and explained. Irregularities in the moon's motion were explained by supposing that the earth did not lie at the center of the moon's orbit, but to one side; and other irregularities in the motions of the sun and planets were explained in a similar way. All motions took place in circles; the circle was the only 'perfect' curve. But the circles were eccentrics; the earth did not lie at their centers.

The periods of revolution of the planets were known to Ptolemy, but he knew little of their distances and nothing of their actual dimensions. The moon, he knew, shone by reflected light from the sun and he explained the lunar phases in this way, as is done to-day. The planets he supposed to shine by their own light, just as the fixed stars do. Astronomy to-day asserts that the planets, like the moon, shine by reflected light, and that the fixed stars are suns situated at immense distances.

Ptolemy solved the problem of the universe by solving the problem of the motion of each planet separately and by annexing each solution to the others. He never sought, it seems, for a single law governing all the cases. But such a law is patent. The radii of the epicycles of the superior planets are always parallel to the line joining the earth and the sun. The deferents of Mercury and Venus were

really identical with the sun's orbit. It would seem that these very obvious laws could not escape a geometer of the caliber of Ptolemy. It appears that he never attempted the generalization; nor did his successors till the time of Copernicus. Each case was treated separately. When each was solved the explanation was complete. It required fourteen hundred years to make a generalization which is, in reality, simple, almost obvious.

Ptolemy's explanation of the system of the world accounted for all the facts known to him. As time went on, those assiduous observers, the Arabians, discovered other irregularities in the lunar and planetary motions unknown to Ptolemy. Every new irregularity required a new epicycle to explain it and in time the commentators of Ptolemy had added cycle on cycle, orb on orb until more than sixty spheres were necessary. The system lost its simplicity as more and more facts had to be explained and became a tangle of single instances, a web of particularities. It was never refuted. It broke of its own weight. The heliocentric hypothesis of Copernicus explained all these matters so simply, so convincingly, that it was soon adopted by all competent persons who examined it. The simplicity of a hypothesis is, of course, no evidence of its truth. Many modern theories are complex to a degree, but this is no proof that they are not true.

A layman seldom understands the attitude of a man of science towards 'theories,' as they are often half-contemptuously termed. Theory is popularly used as a synonym of opinion. 'His theory' is thought of as merely 'his opinion.' When, let us ask, is a science perfect? It is perfect when the circumstances of a phenomenon that is to occur in the future can be as accurately predicted now, as they can subsequently be observed when the actual phenomenon occurs. The 'theory' of transits of Venus over the sun's disc is practically perfect. We can predict the conditions of the next transit in A. D. 2004 almost as well as the astronomers of that day can observe it. The theory of Neptune's motion is so well known that the position of the planet in 1999 can be now predicted almost as accurately as it can be observed in that year. The theory of the circulation of the sap in plants is, on the other hand, far from perfect. We understand its general laws very well, but it is quite impossible to predict the circumstances for any particular plant in any particular season. The theories of hail, of lightning, of auroras and many others are in the same state.

It is obvious that if our own methods and instruments of observation are greatly improved at any particular epoch the science to which they belong will cease to be perfect even if it were a perfect science in the first instance. Tycho Brahe observed the longitudes of the stars by the naked eye. It is impossible, as we now know, to fix a longitude by such observations within one minute of arc (1′). This depends on the very constitution of the eye. When the telescope was

invented and provided with a micrometer it became possible to fix star-places to within about one second of arc (1″). Tycho's observing science, perfect in his day—incapable of further improvement—was no more than a rude approximation to Bradley, Astronomer-Royal of England in 1750. Bradley's tests were at least sixty times more delicate (1′ = 60″). Examples of this sort show how theories are held. Certain tests are now available—tests of a certain delicacy. When phenomena can be predicted beforehand as well as they can be subsequently observed, science is perfect up to that point. Increase the delicacy of the tests and a new standard is set up. Wave-motion was pretty well understood at the end of the nineteenth century until the X-rays came and refused, at first, to be reflected, refracted or polarized.

We in our day have learned a patient tolerance of opinion; wait, these theories that seem so baseless may, perhaps, come to something, as others have done in the past. To what especial and peculiar merit do we owe this acquired virtue of tolerant patience? It is owed solely to the experience of centuries. We have so often seen the impossible become the plausible, and at last the proved and the practical. Can we justly expect that our frame of mind—the strict result of centuries of experience—should have been the attitude of the doctors of the middle ages? Galileo was a great physicist: would not even he require time to accept our modern cobweb theory of the constitution of matter with its ether, molecules, atoms, electrified and non-electrified half-atoms, ions, dissociation, radio-activity and the like? Centuries of experience have taught us to hold theories lightly even while we are using them for present interpretations of phenomena. What physicist doubts that our present theory of electricity needs a thorough-going revision? And yet, who fails to use it where it can serve even a temporary purpose, foreseeing all the while new interpretations in the future?

The fundamental necessity in studies like the present is to *realize* the state of mind of our heroes and of the communities in which they lived. The only data are the words of the books they have left us.

How to interpret their words *in their sense* is the central difficulty; it is often most misleading to interpret them in our own. 'Do unto others as you would that they should do to you' is a golden rule that has been given in nearly the same words by Aristotle, by Christ and by Confucius; yet by 'others' Christ meant all men; Aristotle meant all the free born men of Greece, not their slaves; and Confucius meant the virtuous among his countrymen and excluded all wicked men and all foreign barbarians. If we consider what was meant by the words 'citizen,' 'honor,' 'duty,' in ancient Rome; in the later Roman Empire; in Constantinople; in the free towns of Italy; in the England of the

middle ages; we shall understand the snares that lie latent in words which at first glance seem obvious in meaning.

In comparing the view-point of different ages with our own we continually meet with surprises. The uncritical attitude of the men of the thirteenth century towards miracles and wonders is little less than astounding to us. Our thought seems to be ages in advance of theirs. On the other hand, we often meet with an insight that has what we call the distinctly modern note. An instance from literature will illustrate:

A man's character is his fate

is a sentence that one would assign to Taine or to Stendhal in the nineteenth century, if one did not know it to have been written by Heracleitus in the fifth century before Christ. In like manner, some of the scientific processes of Hipparchus, Archimedes and Roger Bacon are so 'modern' as to bring a glow of delighted wonder when they are met with. Their failure to draw certain conclusions that seem almost obvious to us is equally astonishing. A formal explanation of the differences and of the resemblances of ancient ages with our own may be had somewhat as follows. We may suppose that a completely developed man of our day has educated his sympathies and intelligence to have outlets in a certain large number of directions—let us say, in the directions

A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z.

It is possible, however, that some few of these outlets are absent, or nearly closed, E and O for instance. The men of the eighteenth century may be supposed to have had fewer outlets, and those of the thirteenth still fewer; but the intensity and refinement of their sympathies in certain directions may not have been less but greater than ours. The feeling of the thirteenth century for religion, and of the sixteenth for art, for example, were not only different in intensity, but very different in quality from our own. When we make a formal comparison of our age with that of St. Thomas Aquinas and of Newton the table might stand thus:

A, B, C, D, –, F, G, H, I, J, K, L, M, N, –, P, Q, R, X, Y, Z..twentieth century
a, b, c, d, e, f, g, h, i, –, –, –, m, n.....thirteenth century
a, b, –, –, –, –, g, h, i, j, k, l, m, n, o, p, q, r.....eighteenth century

If in a comparison of the thirteenth century with our own the discourse is upon the matters A, B, C and D we may find their insights, a, b, c, d, singularly like our own. The case may be the same for the matters G, H, I compared with g, h, i. But if, by chance, we are comparing their insight e with our absence of insight or our X, Y, Z, with the blanks in their experience, we are astonished at the difference of outlook. This formal and unimaginative illustration may not be quite useless in clarifying one's thought upon a matter easy to describe in words and exceedingly difficult to realize. It is essential

to admit the presence of blanks in the experience of past centuries; and also the presence of insights upon fundamental matters astonishingly different in intensity and in quality from our own. The experience of the thirteenth century was handed onwards to succeeding ages; it could be understood by the ages near to it; words continued to mean in the fourteenth very nearly what they meant in the preceding century. But as ideas changed, the signs for ideas changed with them; and we must be constantly on our guard lest we unthinkingly admit an old form as if it had the new meaning.

Consider, for example, what astrology meant to Roger Bacon and what it means to us. He had no difficulty in reconciling the fateful influence of the stars with a scheme of salvation for men possessed of free-will. Words had different meanings to him and to us. His mind was conscious of no conflict between his religion and his science. His religion—that of the thirteenth century—is in absolute conflict with our science—that of the twentieth. Let his one example stand as a type of many that might be brought forward.

In what follows we shall study the words of Roger Bacon, the highest product of the thirteenth century.* His *Opus Majus* has recently (1897) been admirably edited by Bridges. Bacon has there expressed himself fully; and his century can be understood by implications. For this reason—to recreate, as it were, the background upon which the figure of Copernicus is projected, I have set down a few sentences. The paragraphs chosen relate chiefly to science, in which Bacon was far advanced, but enough is given of his views of philosophy, theology and morals to assist our judgment of his time. These extracts show what was possible to a man of the thirteenth century; and Bacon did not stand alone. He is the representative of a spirit that was active and widespread. It was creative; and it formed the scientific thought of succeeding centuries. Extracts from the summary of Bridges follow:

OPUS MAJUS.—The four general causes of human ignorance—(1) subjection to unworthy authority; (2) habit; (3) popular prejudice; (4) false conceit of our own wisdom. Popular prejudice is a potent cause of error—pearls should not be cast before swine. Aristotle, wisest of philosophers, was not perfect. Avicenna sees where Aristotle erred; Averroes corrects Avicenna. Errors are found among the fathers of the church. By the habit of discussing received opinion we cease to be its slaves. The best Greek thought was not known to the Latin fathers. The early church made no use of Greek science, and the same is true of Bacon's own day, though without a good excuse.

The Connection of Philosophy with Theology.—Reason comes from God, therefore philosophy is divine. It is not an invention of heathen nations. The business of philosophy is to furnish a criterion of knowledge. All speculative philosophy has moral philosophy for its end and aim.

* See a paper on Roger Bacon in THE POPULAR SCIENCE MONTHLY, January, 1902.

The Study of Language.—The quality of one language can never be perfectly reproduced in another; Latin altogether lacks many necessary words; a translator must not only be perfectly acquainted with his subject, but also with the two languages with which he deals; the translators of Aristotle have not fulfilled this condition; errors remain in the Vulgate; Hebrew, Chaldean, Latin, Greek (and Arabic) should be studied.

Mathematical Science is the key to all sciences; astronomy depends on mathematics; things terrestrial no less, since they are governed by things celestial.

Rays issuing in infinite number from a point in every direction find their termination on the hollow surface of a sphere. Light and other forces propagate themselves in this way. By the foregoing principles and others akin to them all natural actions are to be explained—as, for example, eclipses. (The moon and planets are self-luminous.) Refraction is discussed. The varying heat of different regions of the earth at different seasons is explained.

The emanations from the stars affect not merely climate but character; implanting in the new-born child dispositions to good and evil: though free-will, God's grace, temptations of the devil, or education may modify these innate tendencies. (Temperament is itself a result of the influence of the stars.)

The theory of (radiations of force) may be applied to the tides. These evidently depend on the moon. It is still unexplained why tides occur in the hemisphere averted from the moon.

On geometrical grounds the shape of the universe may be inferred to be spherical. The water, air and the fire surrounding the earth concentrically are of similar form (the sphere of fire is neither luminous nor visible).

In a body falling towards the earth's center a strain is involved; from this strain, heat results; experiment shows this to be a fact.

The Application of Mathematics to Sacred Subjects.—Astronomy shows the insignificance of the earth as compared with the heavens. The smallest of the stars is larger than the earth. Chronology is dependent upon astronomy. The lunar periods are discussed.

The rainbow is produced by the solar rays striking on the raindrops and being refracted or reflected thence.

One degree of latitude is 56 miles. The semi-diameter of the earth is 3,250 miles. The distance of the starry sphere (according to Alfraganus) is 130,715,000 miles. The distances of the planets are given—Saturn's as 65,357,500 miles (it is in fact 886,000,000) and the moon's 208,541 (it is in fact 238,840).

There are 1,022 fixed stars catalogued, The largest are 107 times as large as the earth; the smallest 18 times. Besides these there are infinite numbers of other stars.

Astrology as it relates to church government is discussed. Christianity is associated with the conjunctions of the planets Jupiter and Mercury; the extinction of religions is related to the conjunctions of Jupiter and Saturn with the moon.

The correction of the *Church Calendar* is discussed. At the present time its errors are so great as to attract the ridicule of Jewish and Arab astronomers.

Geography is discussed at length. The space of ocean separating Spain and India is inconsiderable; the seven climates of Ptolemy.

Astrology.—The sun may be said to beget no less than the parent. Each planet has an influence. Special parts of the body are affected by different constellations. The bearing of this on medical art is obvious. The comet of 1264 was due to Mars, and it was related to the European wars of that year.

Optics.—The organs of vision, psychical and cerebral; the organs of the sensitive soul are in the brain; threefold division of the brain; the heart is the

seat of life; the brain first receives impressions; the nerves; the anatomy of the eye; its humors; the function of vision; vision is the result of radiation; vision is not completed in the eye but in the brain; matter is infinitely divisible; as many divisions can be made in a grain of millet as in the diameter of the world; theory of color; conditions of vision; time is required for the propagation of light; double images; radiations from the object and from the eye; perception; the Milky Way is a multitude of small stars clustered; shooting stars are probably bodies of small magnitudes seen by (persistent vision); phases of the moon; the surface of the heavens is spherical; illusions respecting relative motion; twinkling of stars; animals pass through a train of mental processes akin to syllogistic reasoning, though they can not put it into a logical figure; they have a storehouse of mental impressions; can generalize and draw conclusions.

On Reflected Vision.—The angles of incidence and reflection are equal whether the mirror be plane or spherical; mirrors; illusions; color; refraction; by refraction great wonders may be wrought; small things may be made to seem great, distant things near.

Moral Philosophy.—Civic morality; personal morality; we must pursue our steady course, not diverted from it by the varying blasts of opinion; proof of the truth of the Christian religion; revelation is necessary; it is not enough for the reason to be convinced in this matter—the heart must be stirred. If we are made one with God and Christ, to what greater good can we aspire?

The thirteenth century is memorable by the appearance of three great men, Roger Bacon, Albertus Magnus and St. Thomas Aquinas. Albert was born in Suabia in 1193, the descendant of a celebrated and powerful family. He may be reckoned as the best product of the middle ages. He studied in Padua and Bologna, taught at Cologne and Paris (1245) and returned to Cologne. He became provincial of the Dominicans in Germany in 1254, and was Bishop of Ratisbon (in 1260) till he resigned about 1263. He was the friend of kings and popes. His great service to the church was a systematic presentation of the philosophy of Aristotle with a full accompaniment of Arab commentary. Among his contemporaries he was known as *Doctor Universalis,* and, in the history of the world, is especially famous for his works on physical science. Like all the learned men of his time he was supposed by the vulgar to practise magic and, as a matter of course, he sought the philosopher's stone. It was even currently believed that he paid the large debt of his bishopric of Ratisbon with transmuted gold. The flowers that he grew in the winter time, which the wondering townsfolk called magical, were in all likelihood the product of the first hot-house constructed in Europe. An edition of his works in twenty-one volumes was first published in 1651. This complete collection shows, in the first place, that he was thoroughly familiar with all the learning of the Arabs up to his own time. He was to the west what Avicenna was to the east, an encyclopedia of all knowledge. His philosophy is, of course, Aristotle's, elucidated by the schools of Arabia and Spain. His works on physical science are, in a large degree, mere reproductions of Greek treatises, but they are

nearly everywhere enriched by original observations. In his treatise *De Animalibus* (Vol. VI. of his works) he begins by a study of the spinal column, calls the sponges the lowest forms of animal life, improves on the zoological classification of his forerunners, and includes good descriptions of the fauna of the Arctic, and at the same time admits the legendary monsters of the Bestiaires of the tenth century, the barnacle-goose, *anser arboreus*, for example.

His botany is said to be full of errors. He quotes Pliny's facts relating to the fecundation of the date-palm, and correctly explains them, it is believed for the first time. The term *affinity* is first used in his chemical writings. There was no branch of knowledge that he did not treat, from mineralogy to magnetism, and it is noteworthy that he describes the magnet as in use by navigators in his time.*

It is not necesary in this place to speak of the achievement of St. Thomas Aquinas, the pupil of Albertus. His work does not lie in the field of physics, but in the universe of man. His *Summa* treats more than five hundred questions, but only one section refers to the phenomena of the material world. One remark may be made on the activity of the thirteenth century. Every one of the distinctly 'modern' problems was propounded in that age. Few were solved; but substantially all of them were stated. When a problem is clearly stated it is at least half solved.

The most noted figure in the generation preceding Copernicus was Regiomontanus, who is always thought of in company with his colleagues Purbach and Walther. They formed part of a group of German and Italian astronomers, calculators and teachers, no one of whom made any signal advance, but all of whom were well instructed in the fashion of the time. There are many names of men forgotten to-day among this group; but, on the other hand, the faint beginnings of a critical spirit are here and there to be noted. The *Almagest* was not always taken as infallible; observation began to be accepted as a test of theory. Dominicus of Bologna, the teacher of Copernicus, is a marked example of the new spirit.

George Purbach (or Beurbach, from his native village), professor of astronomy in the University of Vienna, was born in 1423 (died 1461), and studied at Vienna and in Italy. He was a votary of the old astronomy, and his chief work, *Theoricæ Novæ Planetarum* (1460), is a development of the doctrine of crystalline spheres. At the same time he was an ardent student of Ptolemy. The epicycles of Ptolemy were a geometrical conception; the crystalline spheres of Eudoxus and Purbach a crude cosmological idea; they could not be reconciled with nature. In so far Purbach was on the wrong road. He saw, however, the necessity for further observations of the planets and for

* It was introduced into Europe by Flavio Gioja, according to common report, about 1302.

accurate tables to replace those constructed for Alphonso the Wise, which no longer served to predict eclipses or to account for the configurations of the planets.* Errors of a couple of hours in the predicted time of a lunar eclipse were noted, and Mars was two degrees away from its calculated place.

In the work of observation and calculation he gained an invaluable coadjutor in Johann Müller, of Königsberg, a village of Franconia, one of his pupils. Müller called himself, after the fashion of the time, Johannes de Monteregio, but is known to us as Regiomontanus. Together they studied the works of Ptolemy, and together they observed the planets with the best instruments they could construct, though their apparatus was much inferior to that of the Arabs. Like all men of their time they were believers in judicial astrology, and their tables were arranged to meet the wants of this pseudo-science. At the same time astronomy benefited by their investigations, which began to be based on actual observation of the sky.

The Papal Nuncio in Vienna was then Cardinal Bessarion, once Bishop of Nicaea in the Greek, now high in power in the Latin Church and a friend of learning. Purbach's enthusiasm for the works of Ptolemy was shared by the cardinal, and they planned a new edition of his writings. For such an edition it was necessary to collect Greek manuscripts. After the death of Purbach (1461) Regiomontanus went to Italy in the cardinal's suite for this purpose (1462). Here he remained some seven years, collecting manuscripts, mastering the Greek language, studying the sciences, and writing his treatise on trigonometry. His text of Ptolemy was printed at Basel in 1538 and was used by Copernicus.

In 1471 he was settled in Nuremberg near the printing presses that had been installed a few years earlier. Here he had the fortune to meet a wealthy amateur, Bernhard Walther (1430–1504), who built an observatory for their joint use, and aided him in his publication of various writings, his own and Purbach's. The *Ephemerides* of Regiomontanus made him famous. They were the nautical almanacs of those days, and were used by Columbus and Vasco da Gama in their voyages of discovery. He is also the inventor of the method of lunar distances for determining the longitude at sea. He was invited to Rome by the Pope in 1475 to reform the calendar and there died in 1476.

There is a legend that Regiomontanus was assassinated by the sons of George of Trebizond, the first translator of the *Almagest* of Ptolemy from the Greek, because of strictures passed upon it. The legend

* This great collection of tables was calculated in the middle of the thirteenth century by Arabian and Jewish astronomers, under the patronage of the king, on the system of Ptolemy with some changes. The *Libros del Saber* were an encyclopedia of all the astronomical knowledge of the time and are invaluable to the historian.

is probably not true, but it is, perhaps, worth repeating, as it was credited at the time and casts a light on the age. During his short life Regiomontanus accomplished much, and gave promise of more. In particular he greatly improved the doctrine of trigonometry. Purbach and himself were the very first Europeans to utilize the discoveries of the Arabs in this science. As every astronomical calculation depends upon the solution of spherical triangles, the tables of sines and tangents computed by Regiomontanus were of fundamental importance, since they gave numerical values of these trigonometric functions calculated once for all, and saved the computer endless special reckonings.

It is difficult for us to conceive the state of science in those days. The school-boy problem: given *a, b, c,* in a spherical triangle, to find *A, B, C,* was considered operose by Regiomontanus and his friends, although the solution had been reached long before, by Albategnius. Blanchini, a contemporary of note, sends him the following equations for solution:

$$x:y=5:8;\ x+y=xy.$$

A star rises at Venice at $3^h\,25^m$, and transits at $7^h\,38^m$, after midnight; required its longitude and latitude: is a problem addressed to Blanchini, in return. The Arabs five centuries earlier would have found these questions easy. Regiomontanus was, nevertheless, the most accomplished man of science in Europe. The ancients determined the longitude of a planet somewhat as follows: The difference of longitude between the planet and the moon was measured (*A*) and next the difference of longitude between the moon and the sun (*B*). The longitude of the sun was calculated from the solar tables (*C*). The sum of *A, B* and *C* gave the planet's longitude. In Walther's observatory the angular distances of the planet from known stars were measured and the required longitude and latitude of the planet were calculated, by the formulæ of spherical trigonometry, from the known longitudes and latitudes of the stars. The gain in precision was considerable, and the observations could be made on any clear night, whether the moon was or was not above the horizon.

Walther survived his friend for many years and carried on the observations which they had begun together. It was in their observatory that clocks (not pendulum-clocks) were first employed to measure short intervals of time and that observations were first corrected for terrestrial refraction. A star seen through the atmosphere appears higher above the horizon than if the atmosphere were absent. Its apparent position must then be corrected for refraction in order to obtain its true place. At an altitude greater than 45° the correction is less than 1′, which was inappreciable before the day of the telescope; but near the horizon the correction is large (the line of sight passing

through the deepest layer of atmosphere there) and must be taken account of, even with rude observing apparatus. Refraction had been studied by Ptolemy and more deeply by Alhazen and Roger Bacon. Twilight, the scattering of the rays of the sun from the particles of dust and the like in the upper atmosphere, was investigated by Peter Nonius (1492–1577) a voluminous writer on astronomical matters.

All that was known in astronomy was familiar to Regiomontanus, and during his seven years' residence in Italy his relations were with the best instructed *savants* of Rome, who were then concerned with projects for improving and correcting the calendar. When Copernicus went to Italy in 1496 the best traditions of all Europe had spread throughout its universities and he was, therefore, familiar with all that his predecessors had accomplished.

A passage from the 'Principles of Astronomy' of Gemma Frisius (died 1558) is worth translation, since it fixes an important date and describes methods of determining longitudes and latitudes which are used to-day. He says: "People are beginning to make use of little clocks that are called watches. They are not too heavy to be carried about; they will run nearly twenty-four hours, and even longer if you aid them a bit; they afford a very easy method of determining longitude. Before starting on a journey, set your watch carefully to the local time of the country you are leaving; take pains that the watch doesn't stop on the road; when you have gone twenty leagues, for instance, determine the local time of the place where you are, with an astrolabe; compare this with the time by your watch, and you will have the difference of longitude." The latitude of the place can be had by measuring the altitude of the pole-star. Watches, which were invented about 1525, varied several minutes a day, and the portable astrolabes of the time could hardly give the altitude so close as 10′; but the methods were correct, and are those to-day employed in using the chronometer and the sextant.

Mention must be made of Peter Bienewitz, otherwise Peter Apianus (born 1495, died 1552), who expounded the Ptolemaic system in a great volume—*Astronomicum Cæsareum* (1540). Apianus was the first to observe the sun through colored glasses. The astronomers of Bagdad had observed an eclipse, when the sun was low, by its reflection in water, and Reinhold had proposed to project the solar image on a card in a camera obscura, a method which was used by the astronomers of Galileo's time. His best contribution to astronomy was the discovery that the tails of comets are generally directed away from the sun, a remark independently made by Fracastor.

Comets in his day were usually supposed to be atmospheric phenomena. Why this connection between them and the sun? Why should the sun, and not the earth, control their forms? The comet of 1472 had been studied by Regiomontanus and its course among the

stars traced. This was the very first occasion upon which a comet had been treated as a celestial body like another. How could an object of the sort circulate among material crystal spheres? Questions of this kind were in men's minds; the observations upon which their solutions must depend were a-making; sufficient progress in mathematics had already been made; the time for a recasting of the accepted theory of the world was at hand.

Crystalline spheres were the basis of the theory of Fracastor. To explain the motions of the heavenly bodies he employed sixty-three spheres whose motions were linked one with another like wheel-work. His doctrine is that: All motions take place in circles; uniform motions are the most probable; each planet always remains at a constant distance from the earth; the changes in their observed brilliancy depend not on changes of distance, but on differences in the earth's atmosphere, or in the density of the crystal spheres; the *Primum Mobile* moves uniformly and always will do so unless God the Creator intervenes by a special act; spheres are of various kinds—conductors, anticonductors, circling, anticircling, countervailing.; sixty-three of them will explain the world; ten orbs belong to Saturn, eleven to Jupiter, nine to Mars, four to the sun, eleven to Venus, eleven to Mercury, seven to the moon. The system of Fracastor is not only complex, but mechanically impossible. It represents the worst aspect of the doctrine which Copernicus was to overthrow and it is interesting as almost the last exposition of its sort, and especially because Fracastor was a contemporary of Copernicus and died in the same year (1543).

THE CONSERVATION OF ENERGY IN THOSE OF ADVANCING YEARS.

BY J. MADISON TAYLOR, A.M., M.D.,
PHILADELPHIA.

THE study of the conditions and changes in the tissues of human beings as they pass beyond middle age would seem at first sight to be of wide-spread interest. Upon the very simplest presentation of the matter it will be universally admitted to be of the greatest importance. The first principle of economics is not so much what we win in any line of industry as what we save; this is the essence of the conservation of values. What matters it how well the child is provided with opportunities for growth and how excellently the young adult is developed in the fullness of such strength as is compatible with individual opportunity; how high a degree of efficiency, mental or physical, can be attained, if all this is to last but for a few brief years of practical utility? Again, allowing ourselves to indulge in a more selfish view, what does it profit us if we shall acquire place and power and the means by which we may be able to enjoy life, as we have learned to live it through years of experience and the exercise of careful choice, if we are to become speedily cut off from the continuance of the enjoyment of those privileges the product of matured judgment and the full energizing of our powers? It is to me a remarkable, indeed an astonishing, fact in searching for data on the subject of senility which one would naturally assume to have grown up in the enormous field of medical literature, that so little is to be found bearing on this subject. There are here and there references to old age and the phenomena of senility in a few of the standard works on physiology, far fewer than the subject would seem to warrant. The subject does not seem to have aroused much interest in the great authorities on medicine, although there are some crisp and vigorous articles which are valuable and interesting.

My own studies have been most largely in the line of growth and development of children and yet interest by no means ends there, and my attention has been drawn to this matter through a constant study based upon part medical research and part individual interest in the whole question of bodily development and the possibilities which lie in this direction for the advance of individual efficiency in all periods of life. It has seemed that the phenomena of degeneration are present in most disturbances referable to those of the nerves and their centers where the analogue of senile changes constantly appears.

Old age has been tritely described as a purely relative term; senility is to be recognized in many persons young in years and is often absent in those of late middle, or even of advanced age. There is no time in the life of a human being when this can be said definitely to begin. It is possible that if the undivided attention and energy of able thinkers were directed toward the means of combating these changes great gains could be made. Indeed notable progress has already been initiated and is being demonstrated with increasing rapidity in prolonging the age of the race through the one avenue of research which is really a development of the last decade. In laying the foundations of constitutional vigor by giving the chief attention to the disorders of children, their proper feeding and hygiene during the first few months of life, the foundation of longevity is capable of being firmly laid. Already there are abundant statistics to prove that the possibilities of retaining vigor to late age in civilized countries is being hopefully revolutionized. Too great praise can not be given to the researches of those men who, with insistent and prophetic voice, have demanded that the infant life shall have better opportunity afforded for prolongation by the regulation of diet and hygiene. If the foundations be well laid the problem of the superstructure can be made a matter of exact procedures. Not only are we of the medical profession becoming keenly alive to this great truth, but the gospel has filtered down and is being rapidly accepted by the great mass of thinkers. It matters little what is done, or what opportunities for growth and development are offered for the nation, if the infant child is neglected, even relatively, in the first three to six months of its life. No skill consistent with modern medicine is able to repair, except in the smallest degree, the irretrievable damage upon that human constitution which has not acquired a fair start in life. Two items of knowledge have been added to the subject of child growth by the clear teachings of such men as Jacobi and Rotch in insisting upon thorough attention to the details of food and nursery life during the period of babyhood. It is possible to find among the histories of those who have attained great age and retained their vigor beyond the ordinary span of life few instances of bottle-fed babies. In the future this will not be so, although at no time can we assume that the same degree of physical integrity can be acquired by artificial feeding as could have been by the natural methods of infant nourishment. Another fact comes up in the histories of very old people that they nearly all spent the earlier months and years of their lives outside of large centers of population.

It is a fact abundantly well known, and yet not of popular knowledge, that constitutional vigor is practically impossible except in the first generation in those who live in large centers without change. Statistics go to show, for London at least, that the fourth generation

of the town dweller is unknown. But enough is currently reported to make the conclusion inevitable that the *sine qua non* of longevity is a certain amount of time spent in the country. The city child is subject to a number of disturbing conditions other than mere absence of creature comforts, which undermine the constitution by throwing too heavy a burden upon the sense organs, through which exhaustion of the central neurons follow; these conditions are such as noises, a perpetual round of hurry, unending sequences of incident exhausting the attention, to which are superadded the physical discomforts of vitiated air and effluvia from human beings and waste organic products, besides offensive gases and infection-laded dust, etc. All these and others more than offset the civic improvements which have their value, of well paved streets and shelter from winds, better housing and many conditions furnished in cities and not in country places. What has been said does not obtain in respect to well conditioned villages and suburbs; at least to the same degree. All this makes for an alteration in the character and quality of symmetrical development. When adult age is reached, these conditions are merely exaggerated. The rush and hurry of competition still interferes with the acquirement of full organic vigor, which demands for its fruition, adequate time and leisure, so that cellular stability may be safely secured. To those of comfortable means, who can from time to time withdraw from the agitating circumstances of city life and enjoy periods of rest and quietude elsewhere, there is less left to be desired. For those who can choose their manner of living, the natural instinct may be trusted to secure selection of those opportunities in the life of most persons which will make for better conditions for continuance of life. To those who have reached middle age, and to whom the desire comes of conserving their powers to the utmost, it is distinctly possible to gain excellent success. So far as the general circumstances of life are concerned, there should be no difficulty in intelligent persons determining for themselves what had best be done. This of course will consist in relieving themselves from worry, strains and anxieties, and in the periodic withdrawal from the hurly-burly of effortful existence; in modifying their diet, in omitting the use of stimulants and narcotics and in spending long periods of time under pleasant conditions, in practical retirement. Above all, amusements should be simplified and accepted rather than sought after. There is enough, Heaven knows, of happiness to be had in keeping the eye, mind and heart open to the enjoyment of those opportunities which lie in the pathways of every one.

It has been my experience to know a number of men and some women who, when the occasion came to them out of the fullness of opportunities for choice, instead of contenting themselves with enjoying life, rushed after such sports as were popular or fashionable, thought to be amusement, and the following of these exhausting pleasures cut

short their career. There will be no difficulty in any one of us searching about in our experience and calling to mind instances of people who had acquired wealth and position, in the enjoyment of good health and relative youth, who yet strove so fiercely to keep themselves (or it may be their thought was for their friends chiefly), supplied with amusements that they fell into the fatal error of doing more than their health would warrant or their constitution sustain.

Perhaps the most important quality, mental or physical, which conditions the attainment and enjoyment of advanced years, is a serene mental view; a capacity for deliberate enjoyment of whatsoever betide. In short a cheerful temperament is as good as an insurance policy; indeed far better. Much might be said along this line of prevention of death by the prolongation of life, but it has been presented to every one of us many times in endless guises and from divers sources. The difficulties are that we fail to realize the practical applicability of oft-reiterated truths which become trite and wearisome and yet are of golden quality and unspeakable value. It is my purpose to offer a few useful hints how one may definitely set about to earn a postponement of the evil days which come upon all, it may be not of ill health, but of a lessening capacity for enjoyment. Heaven has been most cleverly described as being the condition of one who knows what he wants and is able to enjoy it when he gets it, and the reverse of this, Hell, is clearly the atmosphere of that individual who does not know what he wants and could not enjoy it even if he did get it.

Touching the question of self-education in serenity which is admittedly one of the most important accomplishments which any one can acquire, it will be found by each that ever so little attention in this direction will be followed by prompt reward. For instance take the ever present subject of diet. As the effects of age become obstrusive, it is the part of wisdom to omit the use of those stimulating articles of diet to which we accustom ourselves throughout our youth and adult life. It may not be so plain to all, as it is to a man even of my age, how easy and pleasant a thing it is to put aside this or that item of food or drink and substitute for it either less or something different and more suited to our present needs. It is almost a working axiom in the achievement of long life that the less we eat and the less variety of objects eaten, the better. Exceptions will arise; sometimes follies may be committed by carrying these thoughts too far. But in the main it can not be gainsaid, and a great array of conspicuous illustrative instances can be pointed out, that as a working equation, the least should be eaten compatible with existence, to secure the greatest amount of continued health. As will be shown more specifically later, the paramount condition of buoyant youthfulness, whose loss is known to characterize the beginning of old age, is elasticity of the tissues. To preserve flexibility, it may readily be possible, as

has been claimed by some, that this can be done by choice of foods. The use of some articles of diet tends to encourage the deposit of lime salts or to discourage elimination. It may be that by a careful review of the experiences of certain aged folk, we might find a guide to the line of diet by which these good effects can be secured. Old age may not be altogether due to accident in the choice, nor selection of conditions, in the avoidance of accidental damage or trauma. Time will not permit enlargement on this subject now, but there is interesting and instructive reading to be found here and there for those who desire to know. The most notable book devoted to this subject is the 'Autobiography of Louis Cornaro,' whose life was prolonged far beyond that age which is ordinarily thought to be possible, by extreme care chiefly as to choice of diet, and he has set it forth in a most entertaining volume. It is only a partial guide, because temperamental differences must be considered, in the light of the experience of each person, race and community. Families and individuals and nations have different habits of diet. That which might suit one group of cases would not be an exact guide for another, but in the main the principles are the same.

These principles in brief consist in a choice of vegetable and semi-animal foods in preference to red meats. I took a course in physical training long ago under a man who possessed phenomenal vigor, much older than he looked, and he declared that bread, by this is meant leavened bread chiefly, was the most pernicious agent in producing the stiffness of the tissues. This is merely instanced to show how strong convictions are at times, and how they differ from customary beliefs. I do not know how much truth is in this thought, but am of the opinion it is worth attention. Again, the question of the use or non-use of alcohol must be settled for each one. For myself I believe alcohol to be almost altogether bad, although prepared to admit that there may be instances where its use is to be recommended. Some years since there was a popular agitation on the subject of the use of opium. The outgrowth of the opium traffic sanctioned by the British government gave rise to much discussion, which if I have been rightly informed was carried on both by the government in India and by exportation to China. The contention waxed hot and almost all the testimony was against the traffic and encouragement of the use of this baneful drug. In the midst of this, however, Sir Joseph Fayrar, at that time the one chief in authority in medical politics in the government of India, wrote a most powerful and able defence of the use of opium, particularly its habitual use, in which he showed that among certain races, especially those of the Orient, opium was not followed by the destruction of mind and body which it is our custom to consider inevitable. He gave instances, numerous and convincing, that by the use of this drug or food, as it might possibly be called, a large num-

ber of intelligent, indeed most wise and capable Hindoos, had acquired great length of days without impairment to their best powers.

All such matters must be discussed with due deliberation and full knowledge of all attainable facts. The topic at the time interested me exceedingly, and in the course of a research which I made upon the causation of mental impairment, imbecility and idiocy, I became convinced that the use of opium by the individual was of relatively little harm in some exceptional instances. It certainly does not seem to be as hurtful as the habitual use of alcohol. So far as the effect of these poisons, for poisons they are, upon the second generation, it was shown that alcohol produced infinitely worse results upon the second and third generation of those that used it than followed the use of opium.

Close to the realm of deliberate thought and rational conclusions comes the debatable ground of varying opinion. The study of the life history of aged people would furnish much of value if it could be undertaken judiciously and thoroughly studied. The opinion of these or those old persons as to what article of diet, the use or omission of which aided them to acquire their age, comes close up to the realm of conjecture. As an instance of my study may be cited that of a certain lady, famous in my city for wit and wisdom, and who attained a ripe old age with apparently no diminution of her powers. She was on one occasion presiding in a distant city over a meeting of Colonial Dames, and was regarded as almost a prophetess by many, both friends and strangers. She told me that a certain lady approached her with much deference one morning and asked with bated breath if she would be so good as to tell her to what she attributed her great age and elasticity of mind and body. In the way of a joke she told her that it had always been her custom to eat great quantities of salt; and in relating the story to me, this lady said that she had no doubt that by this time that stranger was thoroughly well pickled in endeavoring to follow her lead.

It must always be borne in mind that old age is an inexact term. During the middle ages, statistics would seem to show that the recognized span of life was much shorter than it is now. As an instance of this, Old John of Gaunt, who was a byword, throughout many troublesome years, of age and wisdom, yet died before he was sixty. Warwick, the King Maker, whose history lapsed over that of many sovereigns, is said to have died at the age of fifty-four. In our own time great improvements have been wrought, more particularly within the last quarter of a century, in the matter of increasing the tenure of life, and the average of age has been brought up in a most satisfactory fashion to that which we could not have expected, although optimists have hoped for.

Again, mere existence beyond the ordinary bounds set by nature is of little value unless accompanied by many characteristics and qualities which make life worth living. It certainly should not be a desirable

fate to remain alive and yet lose the capacity of enjoyment or, what is even more important, the capacity of being enjoyed. If it be not an integral part of the personality of an old man or woman to present qualities of attractiveness to others, the fullness of life has not been attained. The factors which go to make up the quality of desirable and admirable old age are above all, first and foremost, self respect, an interest in the affairs of others, a dignity and kindliness, a patient and uncomplaining endurance and a capacity constantly exercised to be of use in the world. A woman, for instance, can if she give her undivided attention to it, grow old so charmingly that she may at great age attain more grace and fascination than she had in her youth or middle life. We all know instances of this truth though some are thus more blessed than others. A man again may become a greater power for good even when well past the age of so-called usefulness than at any previous time. Nor do these qualifications depend necessarily so much upon the original structure of mind or body as the maintenance of a faithful vigilance and conscious desire to be, and do, that which shall furnish forth these good attributes.

The principles of action upon which the effects of advancing years may be postponed are simple, clear and practicable. The difficulties are chiefly the indifference or indolence which age begets. Wherever a person has acquired an active desire to retain the freshness of youth and is moderately diligent in pursuing whatever means should be adopted, the results are successful often beyond expectation. The conditions of success are an original soundness of constitution and fairly healthy organs. It might be added reasonably comfortable circumstances, but I know several cases where the environment was far from satisfactory, and daily labor onerous, yet these people were not discouraged. One other condition might be mentioned as needed often, but not constantly, viz., the counsel of a wise physician. Medical advice ought to be more frankly and constantly sought for the lesser infirmities of age than during middle life for reasons obvious. As the internal resistances lessen small disorders more readily throw the actions of the organism out of balance, and fatal results follow seemingly small causes. Another prerequisite is consistency and persistence in the measures employed. The balance of power in the old is not easily retained, and regained with far greater difficulty. It is an axiom among horsemen that an old horse can be kept fit if used carefully and constantly, but once allowed to get into poor condition through disuse it can never be reinstated.

The potentiality of cellular cleanliness, and lymph activity, on the mechanism of life is paramount, and is not yet duly appreciated by men in or out of the profession of medicine.

Diet has been alluded to already and all that it is needful to say here is to repeat that temperance in food and drink is an essential

condition of the best results. Regularity of conduct is important both in bodily habits and the daily routine of labor or pleasure.

Certain organic defects bear heavily upon the integrity of the ageing organism unless corrected. What miseries have followed unrelieved disturbances of the ears, nose, throat, digestion and eyes in many important lives, can never be fully known. George M. Gould has furnished an amazing lesson in the need for exactitude in correcting refractive errors in the eyes in his analysis of the causes of ill health in later life of epoch making men, among whom are Wagner, Beethoven, Spencer, Huxley, Darwin, Carlyle, Browning, Parkman, DeQûincey (who was thus driven to use opium) and Whittier. The continued usefulness of these men was thus cut short in mid career, let alone the agonies they were compelled to suffer unrelieved.

Open air life is a *sine qua non*. Many old people become hypersensitive to the cold and exposure to the extremes of temperature can become easily fatal. To spend much time in the open air is a guarantee of health, over and above that which was aforetime enjoyed if one has been in the habit of remaining much indoors. It is wise for old people to follow the sun by early rising and going early to bed. To utilize the young morning hours is best for all, but for the aged it is essential. Much sleep is not needed for them, unless they especially crave it as some do and most do toward the end. Dozing during the day is pleasant and salutary, but long night sleep is not necessary as a rule.

The suitability of clothing is deserving of careful study for each. As a rule old people crave much heavy underwear and they are disinclined to expose the skin to the air, and especially to drafts. This is due partly to the lessened activity of the cutaneous capillary circulation, to lowered cellular resistance and blood making power, but also habits and prejudices exert a most potent influence. The readiness with which old people catch cold has more to do with their habits than their age. It is a matter of common knowledge that the products of waste must be more carefully removed in the old than the middle aged. In this the skin must be reckoned as perhaps the greatest eliminating organ and the one most neglected. It is easy to drink lithia water or use other medicines. It is no effort to swallow a pill at night; but unless equipped by a valet or body servant the care of the skin involves personal effort, but one which will amply well repay. Finally, an enormous field of possibilities is opened by studiously striving to retain the fullest elasticity of all the tissues; and to this I desire to call particular attention with some detail and emphasis in the later sections of this article.

The constantly forming poisons invading the nobler tissues require to be removed. If the organic activities can not be relied on, a judicious use of laxatives, diuretics and special baths must be resorted to.

THE GEOGRAPHICAL DISTRIBUTION OF METEORITES.

By Dr. OLIVER C. FARRINGTON,
FIELD COLUMBIAN MUSEUM.

SPEAKING broadly, we know as yet of no fundamental reason why meteorite falls should be any more numerous upon one part of the earth's surface than upon another.

Compared with the vast area of space in which meteorites wander, our earth is but a point, which draws into itself from time to time one of these masses. Moreover, it is a rotating and wabbling point, ever presenting new surfaces to the portions of space in which it is traveling. The marksman who displays his skill by shooting glass balls thrown into the air would have the difficulty of his task enormously increased if he should endeavor to strike successively the same point upon the ball, especially if it had in addition to its forward motion one of rapid rotation about a wabbling axis. It is true that there is some prospect of our being able after much study and comparison of data to locate a few meteorite swarms with sufficient accuracy to warrant a conclusion as to what point upon the earth stones from them will strike, but this possibility seems at present quite remote. At present we can only presume that a gentle rain of meteorites has fallen regularly and impartially upon the earth since the morning stars first sang together.

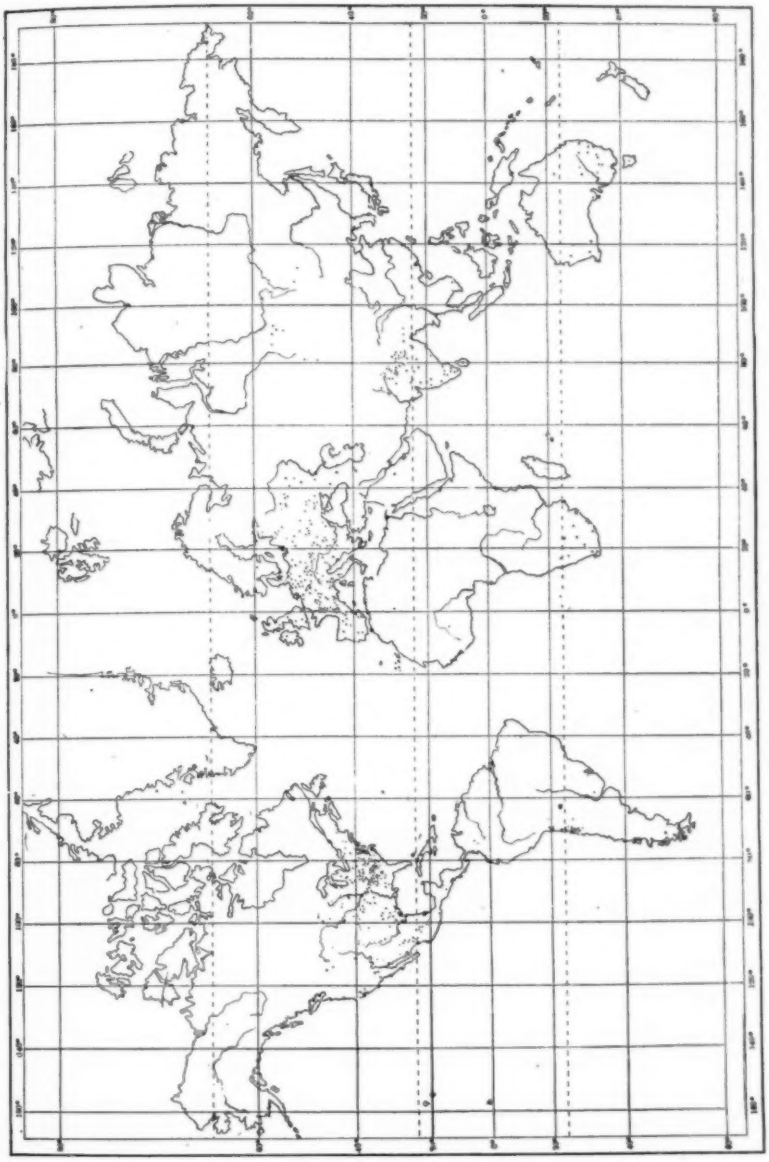
The latest and best calculations, which are by Professor Berwerth, of Vienna, have shown that the number of meteorites actually falling upon the earth at the present time each year, not including of course shooting stars or meteors, is about nine hundred. Two or three of these bodies fall, then, somewhere upon the earth every twenty-four hours. But about three fourths of the earth's surface is covered with water, and the missiles impinging upon this area are lost. Upon the remaining one fourth, however, 225 falls should take place, accompanied by phenomena such as to make the occurrence noteworthy. A large part of the land is, however, unpopulated and our figure of 225 may, therefore, be cut in half in order to take account of this factor. Again, falls taking place in the night would, in many cases, not be observed, and as a last concession we may halve our figure on this account. It would finally seem then that about 55 meteorite falls capable of record might be expected to take place each year, and in a century the total should be 5,500. As a matter of fact, the total number of recorded meteorite falls, including some from as far back as the fifteenth century, is only about 350.

The first conclusion one is likely to draw from results so contradictory is that the original premise is entirely at fault. Yet within the small area of France 50 well-authenticated meteorite falls have taken place within the last one hundred years. We have no reason to suppose France especially favored of the gods in regard to the number of meteorites which it receives and, as it covers only about one one-thousandth part of the earth's surface, we shall find by reversing the calculations made above that our original figure of 900 a year is fully substantiated. The difficulty will be somewhat explained by a glance at the accompanying map. Tracing upon this the locations of known meteorite falls, we see at once that they are largely confined to the civilized nations, or, with the exception of the Semites of Africa and Arabia, to regions inhabited by the Caucasian race. Of a total of 634 known meteorites, 256 are located in Europe and 177 in the United States. In other words, more than two thirds of the whole number known belong to countries which occupy but about one eighth of the land surface.

We reach then the rather curious conclusion that the ability to observe and record meteorite falls is a mark of civilization, and that the relative civilization of regions equally populated may be judged by the numbers of meteorites known from each. The superiority of civilized peoples in this regard comes probably not so much from their greater ability to observe the fall of a meteorite as from their better facilities for recording such an occurrence and for preserving the stone which has fallen. To an unorganized community, the fall of a meteorite is an isolated occurrence, impressive enough at the time, but so infrequent that in the absence of records or means of communication with other communities, it is lost sight of. Civilized communities with their means of records and museums are able to correlate such occurrences, and in time accumulate important knowledge regarding them. So upon the accompanying map there are depicted not only the places where meteorites have fallen, but the isolation of China, the bleakness of Canada, the impenetrability of South America, the hollowness of Australia and the darkness of Africa. Meteorites known from uncivilized countries should for the most part be credited to travelers from civilized nations.

It would be quite superficial, however, to suppose that the distribution of Caucasian peoples is the only important factor affecting the location of known meteorite falls. There are evidences that other factors, the nature of which can hardly be even suggested as yet, affect the place of fall of meteorites. Thus, there appears upon the accompanying map a tendency of these bodies to flock toward mountainous regions. This is indicated by the large numbers of them occurring in India near the Himalayas, in Europe in the vicinity of the Alps, in the United States about the southern Appalachians, and in the Americas

up and down the great western mountain range. It is possible that investigation will show that greater gravitational force is exerted at these points, and that thus the number of meteorites drawn in is there



MAP OF KNOWN METEORITE FALLS AND FINDS UP TO 1908.

increased, or, again, mountains may present actual mechanical obstacles which stop and accumulate meteorites. Whether either of these hypotheses has any foundation in fact, however, is not known as yet.

There are again remarkable differences in the kinds of meteorites

found in the two hemispheres. Thus, taking falls and finds together, of the 256 meteorites known from the western hemisphere, 182 are irons and only 74 stones; while from the eastern hemisphere, of 378 known, 299 are stones and only 79 are irons. Professor Berwerth has sought to account for the excess of irons in the new world by the suggestion that the dry air of the desert areas which abound in this hemisphere has preserved meteorites fallen in long distant periods, while those of a similar age in the other hemisphere have been exposed to a moist climate and have for the most part been decomposed. It is true that many of the iron meteorites known from the western hemisphere occur upon the Mexican and Chilean deserts, but quite as many come from the southern Appalachians, where a comparatively moist climate prevails. There are also numerous desert areas in the old world perhaps as fully explored as those of the new, so that on the whole the above explanation seems inadequate.

Other remarkable groupings of meteorites with regard to their geographical distribution may be noted when areas smaller than hemispheres are compared. Thus of a total of nine meteorites belonging to the peculiar class called howardites, five have fallen in Russia. Of the nine meteorites known belonging to the still more remarkable class of carbonaceous meteorites, three have fallen in France and two in Russia.

Again small areas of equal extent and equally well populated vary curiously in their number of meteorite falls. Within the state of Illinois, for instance, no meteorite is known ever to have fallen, while in the state of Iowa, which has about the same area, but a smaller population, four falls have been noted, and from the state of Kansas, which has a larger area than Illinois, but a smaller and less uniformly distributed population, twelve meteorites are known.

It is usual to dismiss inquiries regarding the meaning of such groupings with the remark that they are mere coincidences. But it is the mission of science to investigate coincidences, and however long the task may be of determining the laws which bring about the particular occurrences here referred to, there can be no doubt that they are the result of law and of law which will some day be discerned by the human mind.

WASHINGTON UNIVERSITY.

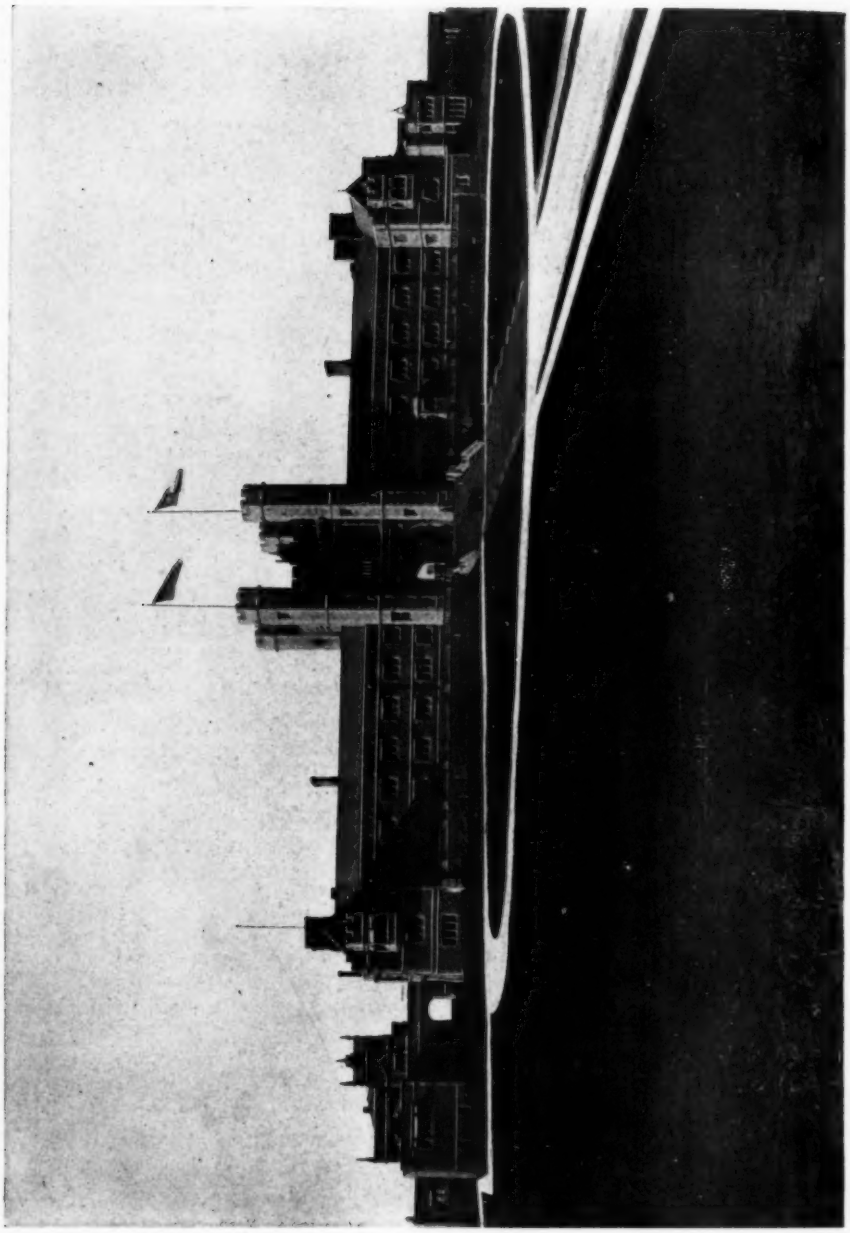
By CHARLES P. PETTUS.

THE organization and establishment of universities, colleges and institutes of learning in the middle west during the half century just past, has been a striking feature in the growth of that section of the country. The act of congress of 1861 to assist state universities by the grant of lands opened the way for the foundation of a number of colleges and universities under state control which have since become great institutions covering all branches of learning, notably the universities of Michigan, Minnesota, Illinois, Wisconsin and Missouri. How well these excellent institutions of higher education have covered the field and supplied the demand for higher learning is shown by the fact that but two important non-sectarian universities, not under state control, have developed in this part of the country, namely, the University of Chicago and Washington University of St. Louis.

Numerous small colleges are to be found throughout all the states, usually under denominational control, and in many instances but little more than high schools, these nevertheless have supplied a certain demand which could not be filled otherwise and have occupied a not unimportant part in the educational system of the country; but the natural location both of Chicago and St. Louis, with a large and populous territory tributary to each of them, demanded university education of the highest type. And the advantages that a great city affords to the student in the many libraries, artistic and scientific museums, hospitals and dispensaries, law courts, manufacturing plants and machinery of all kinds, are such as can not be found outside of a large town.

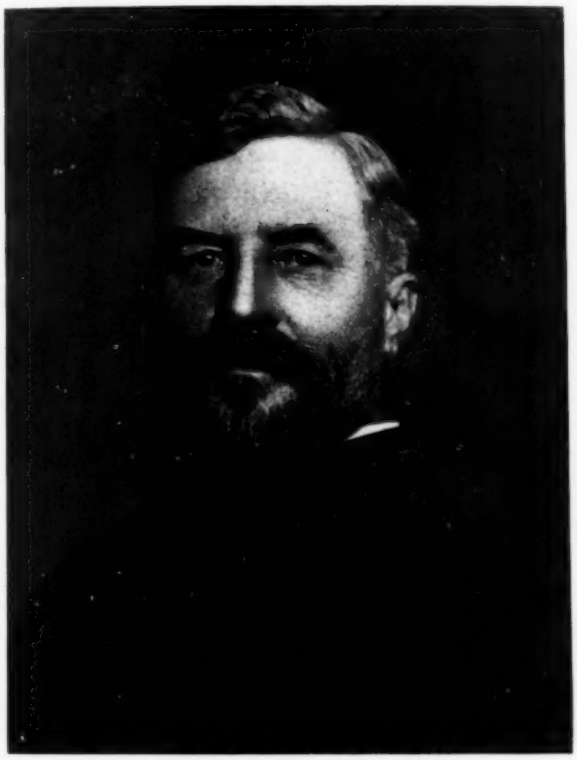
In 1853 Mr. Wayman Crow, then a member of the Missouri state senate, secured the passage of an act of incorporation, approved February 22, 1853, by which a charter was granted to an educational institution to be known as the Eliot Seminary.

This charter, one of the broadest and most liberal upon which any institution is founded, is a perpetual one, and all property belonging to the university is exempt from taxation, city, county and state; and no limitations of any sort are imposed, except those which forbid any sectarian or partisan teaching. So desirous were the founders to avoid any accusation whatever of political or religious bias, that at their first meeting, this eighth article of the constitution was adopted:



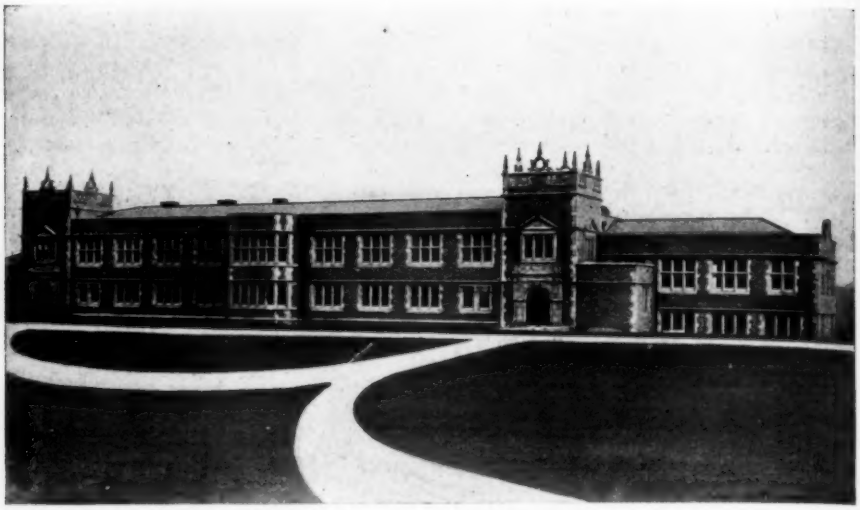
UNIVERSITY HALL.

No instruction either sectarian in religion or partisan in politics shall be allowed in any department of the university, and no sectarian or partisan test, shall be used in the election of professors, teachers or other officers of the university, for any purpose whatever. This article shall be understood as the fundamental condition upon which all endowments of whatever kind are received. Any violation whatever of this article is punishable through the courts.



WINFIELD SCOTT CHAPLIN, A.M., LL.D.,
Chancellor of Washington University.

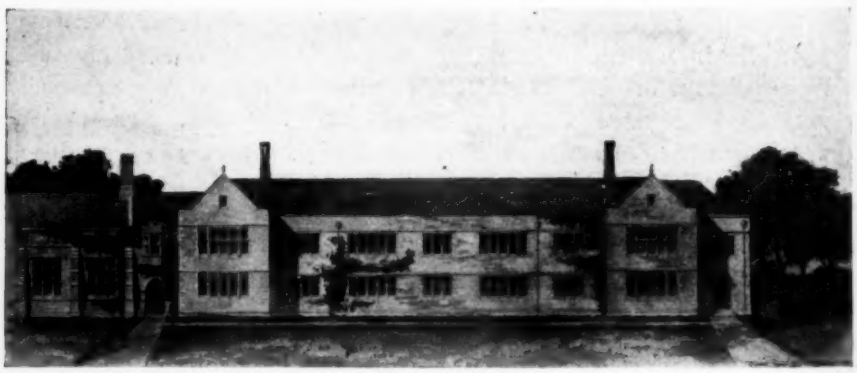
After the lapse of a year, on the twenty-second of February, a meeting of the incorporators was held, the charter accepted and the institution organized under the name of Washington Institute, which name was further changed in 1857 to Washington University. The name was chosen because of its national significance, having also been suggested by the day, February 22, on which the charter was given. The first building was erected in 1853–4, and since that time the university has had a steady and substantial growth, a new department being added when the circumstances warranted it, until to-day Washington University comprehends six departments and has three preparatory schools organized under its charter and, embracing the whole range of university studies except theology, affords complete preparation for every sphere of practical and scientific life.



BUSCH HALL—Chemical Laboratory.

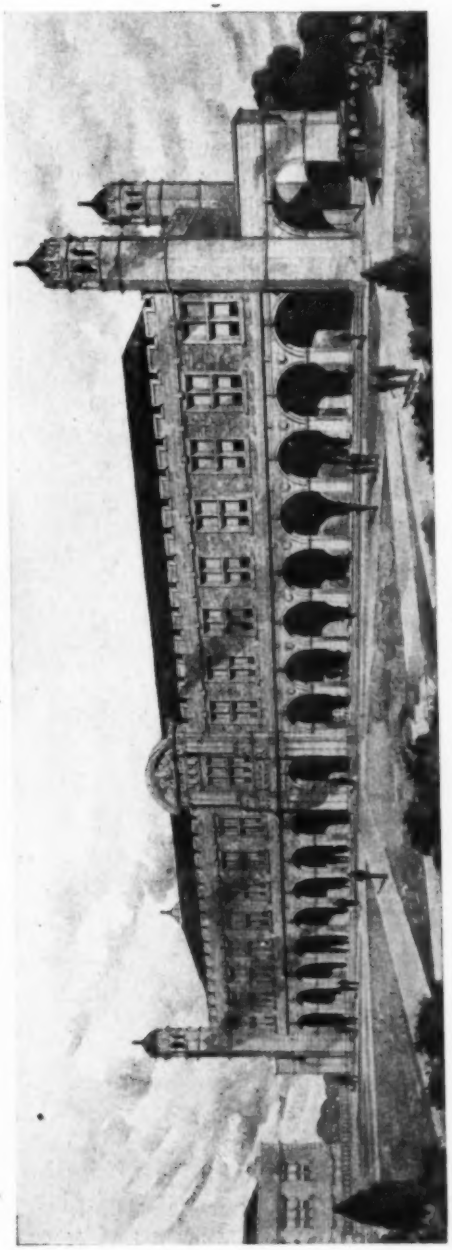
The first board of directors was composed of seventeen well-known influential citizens of St. Louis, who were named in the charter and who were given the power to fill vacancies in their number caused by death or resignation. To this board made up of many of the most prominent and successful professional and business men of St. Louis much of the success of the university is due. Not only have they at all times been most generous in their gifts, but by their careful and broad-minded administration of the affairs of the institution, they have carried it through several financial crises and brought it to its present prosperous condition and to its place of commanding influence in the educational world.

The beginnings, like those of most of the educational institutions of the country that have not had a munificent gift from some philan-



PHYSICAL LABORATORY.

NEW DORMITORIES.



LIBRARY.

thropic millionaire with which to build and equip an entire institution at the start, were necessarily small, and the growth slow, until the public should recognize the worth and value of such an organization and assist it with substantial gifts.

The first building erected by the university was the south wing of the old university group on Seventeenth Street, near Washington Avenue, in which a school was opened in 1856. During the first year 108 scholars were entered in this school, which afterwards became the preparatory department of the university, the name being subsequently changed to its present title of Smith Academy.

On the twenty-second of April, 1857, the formal inauguration of the Washington University took place, with appropriate exercises in Academic Hall and an oration delivered by the Honorable Edward Everett, as well as addresses by the president of the board and several of the directors. This same year, 1857, saw also the erection of a building for a chemical laboratory and the appointment of Dr. Abram Litton to the chair of chemistry. Dr. Litton, 'the first thoroughly trained chemist west of the Mississippi River,'* held this position until 1892.

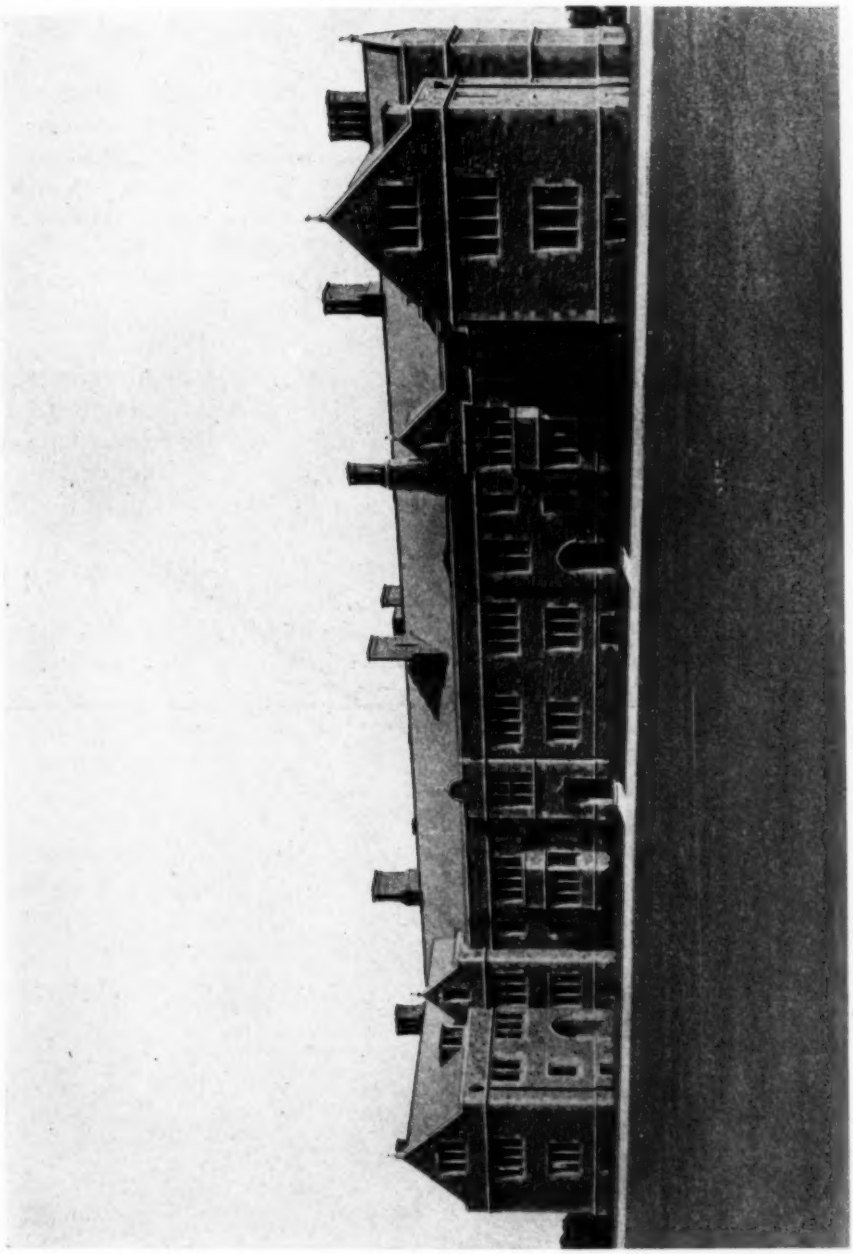
The chair of mechanics and engineering was filled by the appointment of Joseph J. Reynolds, a graduate of West Point, and afterwards Brevet Major-General in the United States Army. The chair of physics and civil engineering was filled by the appointment of John M. Schofield, also a graduate of the United States Military Academy, of the class of 1853, who, after a brilliant record during the civil war, finally reached the rank of Lieutenant-General commanding the United States Army.

Dr. George Engelmann, 'the leading scientist of the west,' was called to the chair of botany; Dr. Charles A. Pope, the celebrated surgeon at the head of the St. Louis Medical College, was made professor of comparative anatomy and physiology, and the Rev. Truman M. Post accepted the professorship of ancient and modern history. With such distinguished men on its first faculty, the influence of the university in the community was at once felt, and the future seemed assured.

During 1858 a college building was erected on the corner of Washington Avenue and Seventeenth Street, and on December 17 of that year Joseph G. Hoyt was elected the first chancellor of the university. Chancellor Hoyt was a native of New Hampshire and a graduate of Yale College, of the class of 1840, and for many years had been professor of mathematics at Phillips Academy, Exeter, N. H. He was a man of scholarship and learning, and of great tact and affability, than whom no one could be better fitted for the young institution.

---

* THE POPULAR SCIENCE MONTHLY, December, 1903, p. 122, footnote.



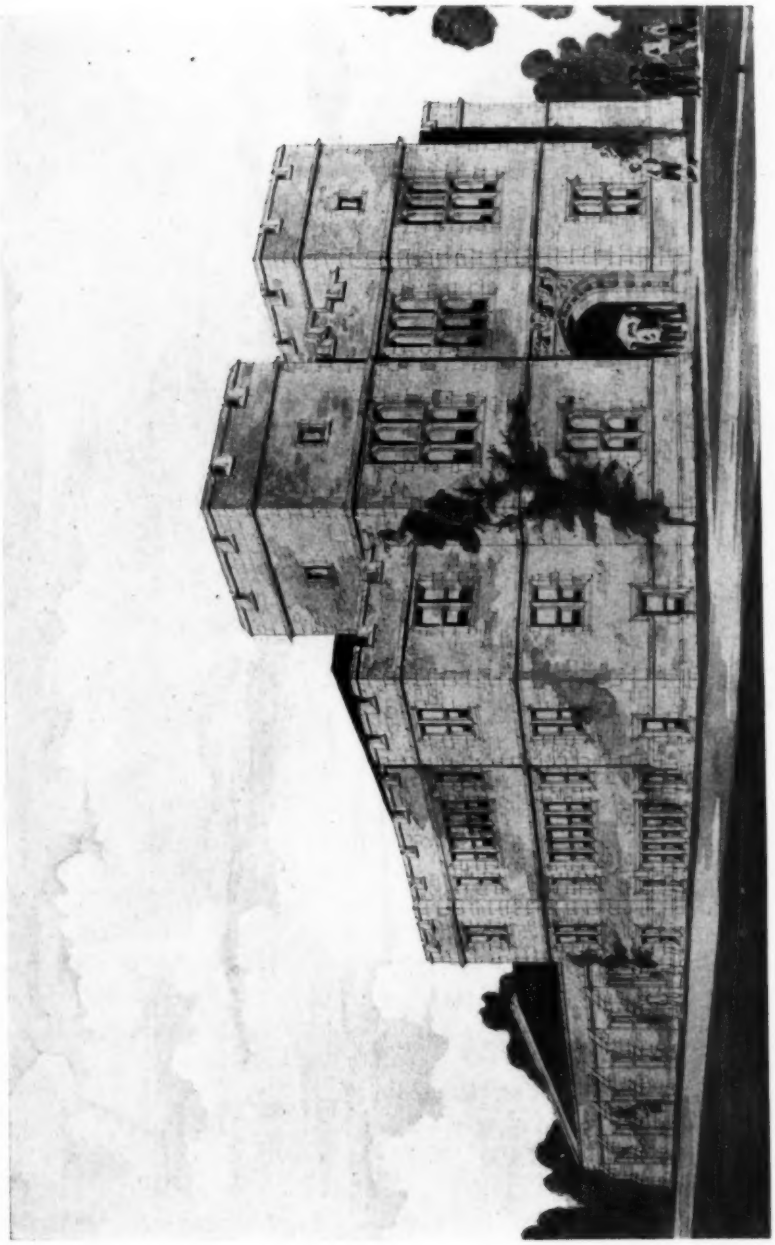
LIGGETT HALL DORMITORY.

Hardly had he taken up his work when the civil war broke out, and for four trying years the university had a hard struggle, handicapped as it was by loss of professors and students, but with reduced resources it braved the storm and continued the work of the institution in all departments. In 1862 the first class was graduated from the college, and in November of the same year, after four years of successful labor, spent in organizing the work of the university, Chancellor Hoyt died. He was succeeded in 1863 by William Chauvenet, who, a year or so before, had been appointed professor of mathematics and astronomy. Chancellor Chauvenet was a classmate of his predecessor at Yale College and a mathematician of national and even of international reputation. He was for some years professor of mathematics at the United States Naval Academy, both at Philadelphia and at Annapolis, and great credit is due to him for his part in organizing that institution, which has always enjoyed such a high scientific position. His textbook on trigonometry is still the standard work in most colleges of this country. For seven years he held the chancellorship, and during his administration a steady growth was maintained. On his death he was succeeded, in 1872, by the Rev. Wm. G. Eliot, the president of the board of directors since the incorporation, both of which positions he continued to hold until his death in 1887.

In 1867 the law school was organized and equipped, and some of the ablest lawyers and judges of the city became members of the faculty. Two years later, in reorganizing the scientific department, courses of study leading to degrees in civil and mechanical engineering and in chemistry were established in this department; in 1870 these courses were lengthened from three to four years, and in 1871 a course of study in mining and metallurgy was added.

And so, finally, we find the work of the scientific department carried on in conjunction with the work of the college, and these two departments soon became grouped together, as the undergraduate department. This union gave final form to the general scheme of the university—a department offering work in arts and science, around which center preparatory and professional schools. Thus, in but a little more than a decade, the university had been organized and the various departments brought into due coordination, leaving the way clear for rapid expansion in the directions which were best adapted to the demands of the times.

In 1878 a new building was provided for the academy, thus separating it completely from the college, and in 1880 the Manual Training School was organized as a third preparatory department. It was the first school of its kind in the country, and its organization is due to Professor Calvin M. Woodward, who was, and still is, professor of mathematics and applied science in the university.

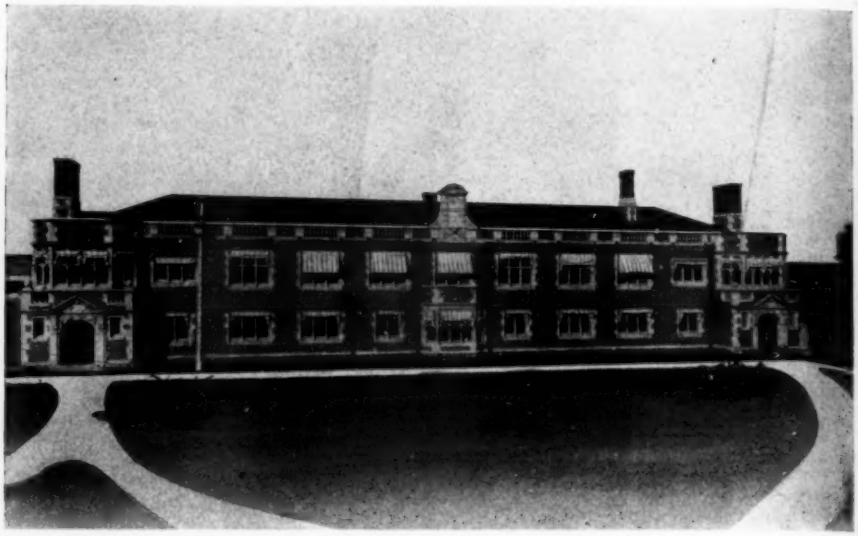


GYMNASIUM.

In 1880 the School of Fine Arts was established and the Museum of Fine Arts was erected and presented to the university by the Hon. Wayman Crow.

In 1885 the Shaw School of Botany was founded and endowed by Mr. Henry Shaw, as a department of the university, in close connection with the Missouri Botanical Garden,* with rare opportunities for advanced botanical research.

In 1892 the Missouri Dental College was made a department of the university, and in 1895 the St. Louis Medical College, organized in 1841, was made the medical department of the university. Two years



CUPPLES HALL NO. 1.
Department of Civil Engineering and Architecture.

later the medical course was lengthened to four years, and in 1898 the Missouri Medical College, founded in 1840, was united with this department, forming one of the strongest departments of the university. As it has at its disposal the combined resources of two institutions of such high standing, it is now one of the best schools of medicine in the country.

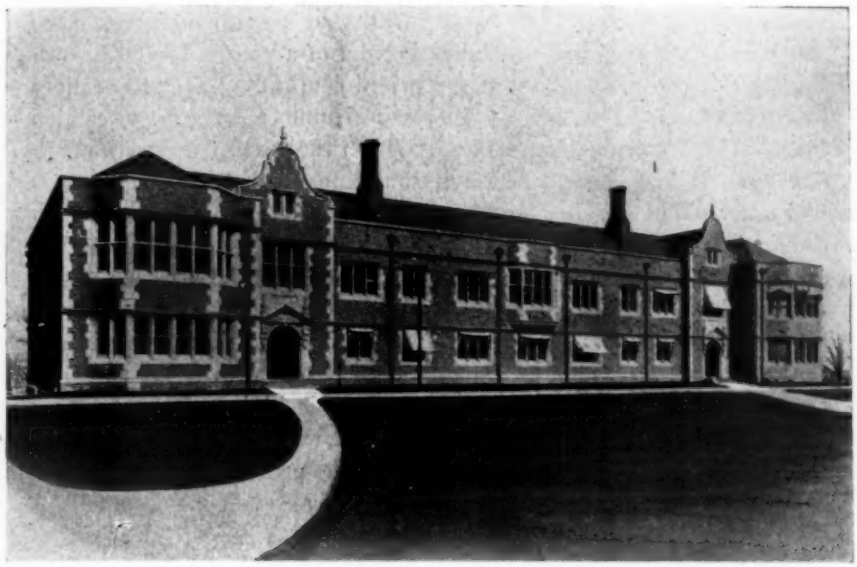
On the death of Chancellor Eliot, in 1887, there was an interregnum of four years, during which Professor Marshall S. Snow, dean of the college, acted as chancellor. He was succeeded in 1891 by Winfield S. Chaplin, the present chancellor, a graduate of West Point, in the class of 1870, who had been successively a professor in Maine State College, in the Imperial University of Tokio, Japan, in Union College

* See THE POPULAR SCIENCE MONTHLY, 1903, for account of Missouri Botanical Garden.

of Schenectady and in Harvard University, where he was also dean of the Lawrence Scientific School.

A high standard of scholarship has at all times been maintained, though often with the loss of students, who could obtain their degrees elsewhere with less labor. That this standard is fully recognized is shown by the fact that a degree from the undergraduate department of the university will admit its holder to the best professional and graduate schools in the eastern institutions.

Until 1892 a regular prescribed course leading to each degree was required, but in the fall of that year the elective system of studies was



CUPPLES HALL NO. 2.
Laboratories of Mechanical and Electrical Engineering.

adopted, and at the same time the scientific department was reorganized and the name changed to the School of Engineering, so that now eight courses of study are offered in the undergraduate department, all requiring four years' work.

COLLEGE.

Elective Course in Arts.

SCHOOL OF ENGINEERING.

1. Civil Engineering.
2. Mechanical Engineering.
3. Electrical Engineering.
4. Chemistry and Chemical Engineering.
5. Architecture.
6. Architectural Engineering.
7. Science and Literature.

The undergraduate department of the university has always recognized that its field of usefulness lay in the city of St. Louis, and no attempt has been made to draw students from a distance. In the early catalogues of the university is found this notice: "Washington University has the advantage of not being incumbered with the dormitory system, which has been proved by experiment to be both expensive and troublesome—a great part of the disturbances so common in collegiate institutions and most of the temptations to which young men in college are exposed, arise from their monastic mode of life, and the consequent removal from the social influence of home."

But in the last fifty years conditions have changed. St. Louis is no longer a small western town of 78,000, but a metropolis of 700,000 inhabitants and the great commercial center of a vast and rapidly growing territory, especially to the south and southwest, and preparations had to be made to receive the increasing number of students coming to St. Louis for university training. Then the westward growth of the city had left the group of university buildings in the midst of factories and other objectionable surroundings. The noise was uncongenial to classic teaching, the passing cars and heavy traffic prevented delicate scientific observations and the dirt and smoke made the situation almost unbearable.

In 1896 a tract of land containing 110 acres on the western border of the city, adjoining Forest Park, was purchased with the intention of moving the undergraduate department to this high and commanding situation. The purchase price of $296,000 was subscribed by citizens of St. Louis, largely through the efforts of the president of the board of directors, Mr. Robert S. Brookings, to whom also belongs the credit of raising an endowment fund of $500,000, of which he gave one fifth, as well as the gift of the Cupples Station, a large group of wholesale business buildings with splendid railroad facilities, valued at $3,000,000, the joint gift of Mr. Brookings and Mr. Samuel Cupples.

An architectural competition was held to select a design for a group of buildings for the undergraduate department on the new site. Plans were submitted by the best architects of the country, and after careful deliberation by an impartial committee those of Messrs. Cope and Stewardson, of Philadelphia, were selected.

The style of architecture is that of the Tudor-Gothic period, and the buildings are constructed of the best red Missouri granite in the most substantial manner, and are thoroughly fireproof; they are all two stories high, thereby avoiding tedious climbing, the lecture rooms and numerous laboratories are large, well-lighted and ventilated, and all the latest improvements in scientific education are included, making them equal, if not superior, to any group of college buildings in the country.

Eleven buildings are now occupied and ready for occupancy by

the university at the expiration of the Louisiana Purchase Exposition which has leased them for the World's Fair period.

University Hall, facing the main approach to the group of new buildings, the gift of Mr. Robert S. Brookings, was erected at a cost of $220,000. The building is 325 feet long, with wings on each end 119 feet long, and the towers 85 feet high. This building will contain the administrative offices of the university, and the offices and lecture rooms of twelve professors, besides study rooms, reception and faculty rooms.

Cupples Hall, No. 1, erected by Mr. Samuel Cupples, at an expenditure of about $110,000, is to be used by the department of civil engineering and architecture. The building is 232 feet long and the width 52 feet. It is two stories high on the quadrangle and three on the north side. The first floor will be used by the department of architecture and the second floor will be devoted to civil engineering.

Busch Hall, the laboratory of chemistry, was presented by Mr. Adolphus Busch and cost $110,000. The building is 291 feet long and about 60 feet wide, two stories high on the north side and three on the south side, and contains laboratories for all branches of chemical instruction and research work.

The library finishes out the first quadrangle and occupies a central position in regard to the group of buildings. It was erected at a cost of $250,000. The eastern front is 257 feet long and the depth is 46 feet, with a reading room one story high in the rear of the center of the building, about 100 feet long and 41 feet wide. The building will contain stacks with room for over 400,000 volumes.

Cupples, No. 2, and the Cupples Engineering Laboratory, directly behind it, were also presented by Mr. Samuel Cupples, and cost together about $165,000. The hall is 207 feet long, the first floor of which is to be devoted to mechanical engineering, and the second floor to electrical engineering. The laboratory adjoining is only one story, but is built in a style uniform with the other buildings, and of the same grade of granite and will contain the engines, pumps, dynamos and motors, etc., as are necessary for instruction in those departments. The university power house close by is provided with a splendid equipment of boilers, engines and dynamos, to furnish light, power and heat for the entire plant.

Eads Hall, the laboratory of physics, the gift of Mrs. Eliza How in memory of her father, Captain Jas. B. Eads, the well-known engineer, adjoins the library on the west.

Farther to the west are two large dormitories both of the same style and construction of the other buildings. Liggett Hall, erected by Mrs. Elizabeth J. Liggett in memory of her husband, the late Mr. John E. Liggett, at a cost of $100,000, will accommodate 75 students,

and the other, built by the university at an expenditure of $190,000, containing a large dining hall, will accommodate 80 students.

At the western end of the university tract is the gymnasium adjoining the athletic field. This building, costing $150,000, is of the bold gothic type, with two square towers facing the east. It contains eight large dressing rooms with showers and lavatories attached, and will accommodate 2,000 men. The gymnasium hall is 75 feet by 108 feet, with overhead running track.

The large athletic field is provided with a grand stand of solid concrete 704 feet long, extending the entire length of the south side of the field, and will seat 7,300 people.

The Washington University Club, on the corner of Twenty-ninth and Locust Streets, is a splendidly appointed club-house belonging to the university and managed by a committee composed of the dean, one alumnus and one student of each department. Membership is open to all officers, to all male professors and instructors of the university, and to all male students and graduates of the college, the schools of engineering and law and the medical and dental departments. The building is admirably constructed and contains dining-rooms, library, smoking and reading-rooms, billiard-room and bowling alleys. The dues are only $5.00 a year, and meals are furnished to students at $3.50 a week. The club has proved of great value in the social life of the university, by bringing together on a common ground the students of all departments, so keeping all the students in touch and helping to create a true university spirit.

With a large and productive endowment, with an efficient faculty, with buildings that will compare favorably with any in the country and with a large enrollment of students in all departments the future growth and usefulness of the university seem to be assured.

WHAT IS GROUP THEORY?

BY PROFESSOR G. A. MILLER,
LELAND STANFORD JUNIOR UNIVERSITY.

IN the recent International Catalogue of Scientific Literature, group theory is classed among the fundamental notions of mathematics. The two other subjects which are classed under this heading are 'foundations of arithmetic' and 'universal algebra.' While it might be futile to attempt to popularize those recent advances in mathematics which are based upon a long series of abstract concepts, it does not appear so hopeless to give a popular exposition of fundamental notions. In what follows we shall aim to give such an exposition of some of the notions involved in the theory of groups.

This theory seems to have a special claim on popular appreciation in our country because it is one of the very few subjects of pure mathematics in whose development America has taken a prominent part. The activity of American mathematicians along this line is mainly due to the teachings of Klein and Lie at the universities of Göttingen and Leipzig respectively. During the Chicago exposition, the former held a colloquium at Evanston, in which the fundamental importance of the subject was emphasized and thus brought still more prominently before the American mathematicians.

There is probably no other modern field of mathematics of which so many prominent mathematicians have spoken in such high terms during the last decade. In support of this strong statement we quote the following:

There are two subjects which have become especially important for the latest development of algebra; that is, on the one hand, the ever more dominating theory of groups whose systematizing and clarifying influence can be felt everywhere, and then the deep penetrations of number theory.* The theory of groups, which is making itself felt in nearly every part of higher mathematics, occupies the foremost place among the auxiliary theories which are employed in the most recent function theory.†

In fine, the principal foundation of Euclid's demonstrations is really the existence of the group and its properties. Unquestionably he appeals to other axioms which it is more difficult to refer to the notion of group. An axiom of this kind is that which some geometers employ when they define a straight line as the shortest distance between two points. But it is precisely such axioms that Euclid enunciates. The others, which are more directly associated with the idea of displacement and with the idea of groups, are the very ones

* Weber, 'Lehrbuch der Algebra,' vol. 1, 1898, preface.

† Fricke und Klein, 'Automorphe Functionen,' vol. 1, 1897, p. 1.

which he implicitly admits and which he does not deem even necessary to enunciate. This is tantamount to saying that the former are the fruit of later experience, that the others were first assimilated by us, and that consequently the notion of group existed prior to all others. . . . What we call geometry is nothing but the study of formal properties of a certain continuous group, so that we may say space is a group.*

From these words of Poincaré it follows that the group concept is implicitly involved in some of the earliest mathematical developments. In an explicit form it first appears in the writings of Lagrange and Vandermonde in 1770. These men inaugurated a classic period in the theory of algebraic equations by considering the number of values which a rational integral function assumes when its elements are permuted in every possible manner. For instance, if the elements of the expression $ab + cd$ are permuted in every possible manner, it will always assume one of the following three values: $ab + cd$, $ac + bd$, $ad + bc$.

The eight different permutations which do not change the value of one of these expressions are said to form a *permutation group* and the expression is said to belong to this group. There is always an infinite number of distinct expressions which belong to the same permutation group. Hence it is convenient for many purposes to deal with the permutation group rather than with the expressions themselves. This fact was recognized very early and led to the study of permutation groups, especially in connection with the theory of algebraic equations. The most fundamental work along this line was done by Galois, who influenced the later development most powerfully, although he died when only twenty years old.

Galois first proved (about 1830) that the solution of any given algebraic equation depends upon the structure of the permutation group to which the equation belongs. As the algebraic solution of equations occupies such a prominent place in the history of mathematics this discovery of Galois furnished a powerful incentive for the study of permutation groups. Before Galois an Italian named Ruffini and a Norwegian named Abel had employed permutation groups to prove that the general equation of the fifth degree can not be solved by successive extraction of roots. In doing this the former studied a number of properties of permutation groups and is therefore generally regarded as the founder of this theory.

The definition of a permutation group is very simple. It is merely the totality of distinct permutations which do not change the formal value of a given expression. Such a totality of permutations has many remarkable properties. One of the most important of these is the fact that any two of them are equivalent to some one. That is, if

* Poincaré, *The Monist*, vol. 9, 1898, pp. 34 and 41.

any one of these permutations is repeated, or is followed by some other permutation in the totality, the result is equivalent to a single permutation in the totality. This property is characteristic; for if any set of distinct permutations possesses this property they form a permutation group and it is possible to construct an infinite number of expressions such that they are unchanged by these permutations but by no others.

Soon after the fundamental properties of permutation groups became known, it was observed that many other operations possess the same properties. This gradually led to more abstract definitions of the term group. According to the earliest of these any set of distinct operations such that no additional operation is obtained by repeating one of them or combining any two of them was called a group. All the later definitions included this property, but they generally add other conditions. These additional conditions are frequently satisfied by the nature of the operations which are under consideration and hence do not always require attention. This may account for the fact that the oldest definition is still very commonly met in text-books, notwithstanding the fact that the ablest writers on the subject abandoned it a long time ago.

The three additional conditions which a set of distinct operations must satisfy in order that it becomes a group when the operations are combined are: (1) The associative law must be satisfied; *i. e.*, if r, s, t represent any three operations of the set, then the three successive operations rst must give the same result independently of the fact whether we replace rs or st by a single operation. The operations are, however, not generally commutative, that is, rs may be different from sr. (2) From each of the two equations $rs = ts$, $sr = st$ it follows that $r = t$. (3) If the equation $xy = z$ involves two operations of the set the third element of the equation must also represent an operation in the set. It may be observed that the totality of integers combined by multiplication obey all these conditions except the last. Hence this totality does not form a group with respect to multiplication, although the contrary has frequently been affirmed.*

One of the simplest instances of a group of operations is furnished by the n different numbers which satisfy the equation $x^n = 1$. It is very easy to see that these numbers obey each of the four given conditions when they are combined by multiplication. Hence we say that the n roots of the equation $x^n = 1$ form a group with respect to multiplication. Since all these roots are powers of a single one of them

* Among other places this error is found in the first edition of Weber's classic work on algebra, vol. 2, p. 54. It has been corrected in the second edition of this work. Somewhat simpler definitions of the term group have recently been given by Huntington and Moore, *Bulletin of the American Mathematical Society*, vol. 8, p. 388.

this group is said to be cyclic. Cyclic groups are the simplest possible groups and they are the only ones whose operations can be completely represented by complex numbers.

Another very simple category of groups of operations is furnished by the totality of movements which leave a regular polygon unchanged. For instance, a regular triangle is transformed into itself when its plane is rotated around its center through 120° or through 240°. Moreover, its plane may be rotated through 180° around any of its three perpendiculars without affecting the triangle as a whole. These five rotations together with the one which leaves everything unchanged (known as the identity) are all the possible movements of the plane which transform the given triangle into itself. Hence these six movements form a group, which happens to be identical with the group formed by the six possible permutations of three things.

It is not difficult to see that a plane can have just eight movements which do not affect the location of a given square in it. These consist of the three movements around the center of the square through 90°, 180° and 270° respectively; the four movements through 180° around the diagonals and the lines joining the middle points of opposite sides; and the identity. This group of eight operations has exactly the same properties as the permutation group on four letters which transforms $ab + cd$ into itself. Hence these two groups are said to be simply isomorphic. From the standpoint of abstract groups, such groups are said to be identical.

In general, a regular polygon of n sides is left unchanged as a whole by just $2n$ movements of its plane, viz., $n - 1$ movements around its center and n rotations through 180° around its lines of symmetry, in addition to the identity. The first $n - 1$ movements together with the identity clearly form a group by themselves. Such a group within a group is known as a *subgroup*. This category of groups of $2n$ operations is known as the system of dihedral rotation groups or the system of the regular polygon groups. It is not difficult to prove that each of them is generated by some two non-commutative rotations through 180° and that no other groups have this property.

Among the non-regular polygons the rectangle with unequal sides has perhaps the most important group. There are clearly just three movements of the plane (besides the identity) which transform such a rectangle into itself, viz., the rotation through 180° around the center and the rotation around its two lines of symmetry through the same angle. These four operations form a group which presents itself in very many problems and is known by a number of different names. Among these are the following: four-group, anharmonic ratio group, axial group, quadratic group, rectangle group, etc. Since we arrive at the identity by repeating any one of its operations, it is entirely dif-

ferent from the group formed by the four roots of the equation $x^4 = 1$. It is easy to prove that these two groups represent all the possible types of groups of four operations; that is, there are only two abstract groups of four operations. In general, the number of groups which can be formed with n operations increases very rapidly with the number of factors of n. When $n = 8$ or 12 the number of possible abstract groups is 5.

Similarly, all the movements of space which transform a given solid into itself form a group. For instance, the cube is transformed into itself by twenty-four distinct movements. Nine around the lines which join the middle points of opposite faces, six around those which join the middle points of opposite edges, eight around the diagonals, and the identity. The group formed by these twenty-four movements is simply isomorphic with the one formed by the total number of permutations of four things. The regular octahedron has the same group, while the group of the regular tetrahedron is a subgroup of this group. The icosahedron and the duodecahedron have a common group of sixty operations. The groups of the regular solids play an important rôle in the theory of transformations of space. They are treated at considerable length in Klein's 'Ikosaeder' as well as in many other works.

All the preceding examples relate to groups of a finite number of operations, or of a finite order. During recent years the applications of groups of infinite order have been studied very extensively. As the theory of groups of finite order had its origin in the theory of algebraic equations, so the theory of groups of an infinite order might be said to have had its origin in the theory of differential equations. The rapid development of both of these theories is, however, due to the fact that much wider applications soon presented themselves. This is especially true of the latter. In fact, the earliest developments of the groups of infinite order were made without any view to their application to differential equations.

One of the simplest examples of groups of infinite order is furnished by the integral numbers when they are combined with respect to addition. The totality of the rational numbers clearly becomes a group when they are combined with respect to either of the operations addition or multiplication. The same remark applies evidently to all the real numbers as well as to all the complex numbers. These additive groups of infinite order are frequently represented by the equation $x = x' + a$, where a may assume all the values of one of the given groups. If a may assume all real values the group is said to be continuous. When a is restricted to rational values the group is said to be discontinuous, notwithstanding the fact that it transforms every finite point into a point which is indefinitely close to it.

While these examples exhibit a very close relation between continuous and discontinuous groups of infinite order, yet the methods employed to investigate problems belonging to these groups are generally quite different. The theory of the former is mainly due to Sophus Lie and has been developed principally with a view to the solution of differential equations. The theory of the latter has been developed largely in connection with questions in function theory and owes its rapid growth to the influence of Klein. A large part of Lie's results are contained in his 'Transformationsgruppen,' consisting of three large volumes, while the 'Modulfunctionen' and 'Automorphe Functionen' of Klein and Fricke are the best works on the discontinuous groups of infinite order.

Although the notion of group is one of the most fundamental ones in mathematics, yet it is one which is more useful to arrive at reasons for certain results and at connections between apparently widely separated developments than to furnish methods for attaining these results or developments. Its greatest service so far has been its unifying influence and its usefulness in proving the possibility or the impossibility of certain operations. In fact, it is generally conceded that group theory had its origin in the use which Ruffini and Abel made of it to prove that the general equation of the fifth degree can not be solved by radicals.

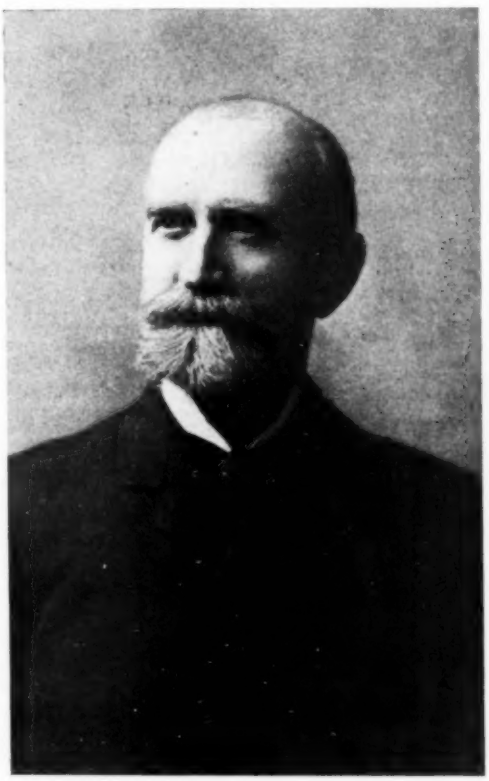
While it may be said to have 'shown its dominating influence in nearly all parts of mathematics, not only in recent theories, but also far towards the foundation of the subject, so that this theory can no longer be omitted in the elementary text-books,'* yet this influence is largely a guiding influence. The bulk of mathematics is not group theory and the main part of the work must always be accomplished by methods to which this notion is foreign. On the other hand, it seems safe to say that this theory is not a fad which will pass into oblivion as rapidly as it rose into prominence. Its applications are so extensive and useful that it must always receive considerable attention. Moreover, it presents so many difficulties that it will doubtless offer rich results to the investigator for a long time.

* Pund, 'Algebra mit Einschluss der elementaren Zahlentheorie,' 1899, preface.

THE PROGRESS OF SCIENCE.

CONVOCATION WEEK MEETINGS OF SCIENTIFIC SOCIETIES.

THERE is an accounting of scientific stock at the close of each year when the national scientific societies hold their annual meetings. There does not, however, exist either for this or any other country a census of scientific work and scientific men. As a rough guess, it may be suggested that there were perhaps 100 men in the United States professionally engaged in scientific work in 1850, 200 in 1860, 400 in 1870, 800 in 1880, 1,600 in 1890, 3,200 in 1900; and that we may expect to find as many as 6,400 in 1910. Certainly the increase in endowments, in opportunities and in men appears to follow a geometrical rather than an arithmetical progression. The American Association for the Advancement of Science held its first meeting in 1848, but the first meeting for which the record of attendance has been pre-

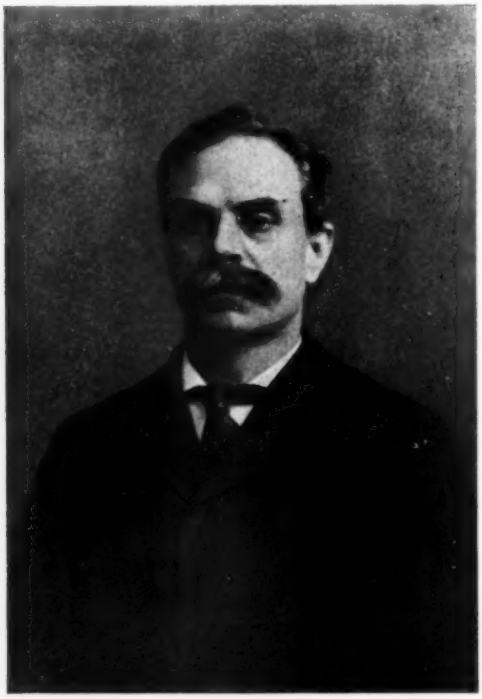


OTTO H. TITTMANN, Superintendent of the U. S. Coast and Geodetic Survey, Vice-president for Mathematics and Astronomy.

served was that of 1851, when 87 members were present. The National Academy of Sciences was incorporated in 1863, and its fifty members included a large proportion of the scientific men of the country. There was no national society for a separate science until the American Chemical Society was established in 1874. Now the American Association is divided into ten sections, and about twenty different societies met in affiliation with it in St. Louis, six societies devoted to the biological sciences met simultaneously at Philadelphia, the Historical and Economic Associations met at New Orleans and the Philosophical Association at Princeton. Nearly every year new national associations are established, which are rarely if ever abandoned. Thus there became this year affiliated with the American Association two new societies—The Society for Horticultural Science and the Society of College Teachers of Education.

A Society for Vertebrate Paleontology held its first meeting at Philadelphia and a Political Science Association was organized at New Orleans.

There were about 500 members of the American Association and affiliated societies at St. Louis, about 200 naturalists at Philadelphia and about 50 philosophers at Princeton. Last year the American Association and affiliated societies held two meetings—one at Pittsburg in the summer with an attendance of about 600, and one at Washington during convocation week with an attendance of about 1,400. The attendance at the winter meeting was consequently this year only half as large as last year, and the attendance of the year only about one third as large. Yet the number of scientific workers increases continually, and the membership



EDWIN H. HALL, Professor of Physics, Harvard University, Vice-president for Physics.

of the association rose during the year from 3,600 to 4,000. The falling off in attendance due to the abandonment of the summer meeting appears to be a definite loss with no compensating advantages. Many members unable to attend in midwinter want a summer meeting, and those who can not travel as far as a thousand miles should be given an opportunity to attend a meeting within reach, and this requires two meetings annually. The summer meeting can also be given certain distinctive features of out-of-door life and scientific excursions, which are out of the question in midwinter. The American Association must be national in scope, but meetings in the central states are always smaller than those on the Atlantic seaboard. The scientific centers in the east are more concentrated, and it is also true that it is psychologically further from the east to the west than from the west to the east. Many scientific men would rather travel 1,000 or 1,500 miles to an eastern meeting than a much shorter distance to a meeting in the central states.

Under the circumstances the St. Louis and Philadelphia meetings may be regarded as successful. They were working meetings of scientific men with nearly as many papers on the programs as members in attendance. In both cities excellent local arrangements were made for the meetings of the societies and sections and for the entertainment of visitors.

WILDER D. BANCROFT, Professor of Physical Chemistry, Cornell University, Vice-president for Chemistry.

We publish above the address of President Ira Remsen, the retiring president of the American Association, and the address of President David Starr Jordan before the Sigma Xi Society. Other addresses of interest were

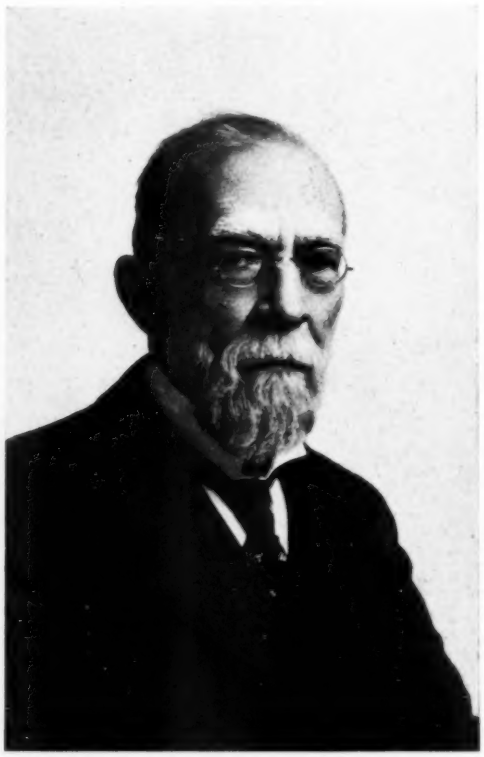
given before the sections of the associations and the special societies, and the public lecture on radium by Professor Rutherford was on a particularly timely topic. The American Association, and it may be hoped all the societies that were affiliated last year in Washington, will meet next year at Philadelphia. New Orleans is recommended as the place of meeting two years hence. Professor W. G. Farlow, the eminent botanist, was elected president of the association. His portrait is given as a frontispiece, and we reproduce here the photograph of the vice-presidents who presided over the sections. Presiding officers for the sections and for the special societies were elected as follows:

Section of Mathematics and Astronomy—Professor Alexander Ziwet, University of Michigan.

Section of Physics—Professor William F. Magie, Princeton University.

Section of Chemistry—Professor Leonard P. Kinnicutt, Worcester Polytechnic Institute.

Section of Mechanical Science and Engineering—Professor David S. Jacobus, Stevens Institute of Technology.



CALVIN M. WOODWARD, Professor of Mathematics and Applied Mechanics, Washington University, Vice-president for Mechanical Science and Engineering.

Section of Geology and Geography—Professor Eugene A. Smith, University of Alabama.

Section of Zoology—Dr. C. Hart Merriam, U. S. Biological Survey.

Section of Botany—Professor B. L. Robinson, Harvard University.

Section of Anthropology—Walter Hough, Bureau of American Ethnology.

Section of Social and Economic Science—Martin A. Knapp, Washington, D. C.

Section of Physiology and Experimental Medicine—The present vice-president, Professor H. P. Bowditch, Harvard University, will serve another year.

The American Society of Naturalists—Professor E. L. Mark, Harvard University.

The Astronomical and Astrophysical Society of America—Simon Newcomb, Washington.

The Geological Society of America—Professor J. C. Branner, Stanford University.

The American Philosophical Association—Professor G. T. Ladd, Yale University.

The American Psychological Association—Professor William James, Harvard University.

Association of American Anatomists—Professor Charles S. Minot, Harvard University.

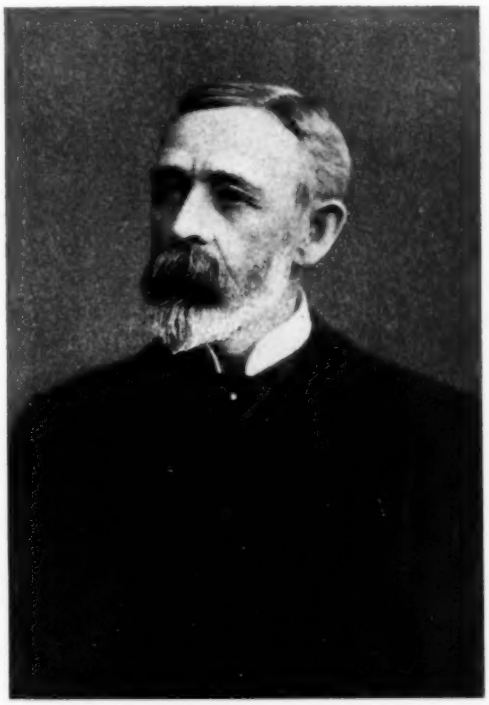
Society of American Bacteriologists—Dr. F. G. Novy, the University of Michigan;

Society for Plant Morphology and Physiology—Dr. G. T. Moore, Washington.

American Physiological Society—Professor Russell H. Chittenden, Yale University.

American Society of Zoologists, Eastern Branch—Professor E. A. Andrews, Johns Hopkins University.

American Society of Vertebrate Paleontologists—Professor Henry F. Osborn, Columbia University.



EDWARD L. MARK, Professor of Anatomy, Harvard University, Vice-president for Zoology and President of the American Society of Naturalists.

THE ST. LOUIS EXPOSITION AND ITS CONGRESS OF ARTS AND SCIENCE.

IT is quite possible that the attendance at the St. Louis meeting of the American Association was somewhat decreased by the fact that many members propose visiting the Louisiana Purchase Exposition and were unable to make the journey to St. Louis twice within a year. Those in attendance at the meeting had, however, the privilege of visiting the grounds of the exposi-

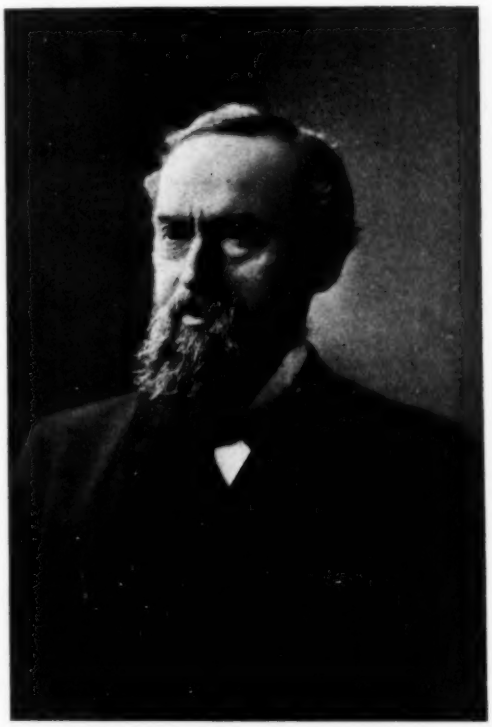
tion and witnessing the extraordinary magnitude of the undertaking. We are told that the approximate cost is $50,000,000, the size of the grounds 1,240 acres, and the area of the buildings 200 acres. It is consequently planned on a scale much surpassing the expositions of Philadelphia, Chicago and Paris. The making of expositions is becoming a sort of applied science, each showing progress over its predecessors. A large proportion of the chiefs of departments and others in charge of the work at St. Louis have been trained at previous expositions.

THOMAS H. MACBRIDE, Professor of Botany, State University of Iowa, Vice-president for Botany.

An exposition is both interesting and tiring, whereas a description is likely to be tiring without being interesting. The subjoined plan gives some idea of the arrangement of the buildings, their number and their size. An enumeration of the buildings shows clearly that the whole undertaking is an apotheosis of applied science, extending even to the shows along 'The Pike.' Education has been given a central place, both in the position of the building, the first to form part of an exposition, and in the classification of the exhibits. The exposition and education are also fortunate in the fact that the new buildings of Washington University are on the grounds. We are glad to be able to publish elsewhere in this number a description of the university which is rapidly becoming one of the great universities of the country. The art gallery is also a permanent building, erected with its temporary annexes at the cost of over a million dollars.

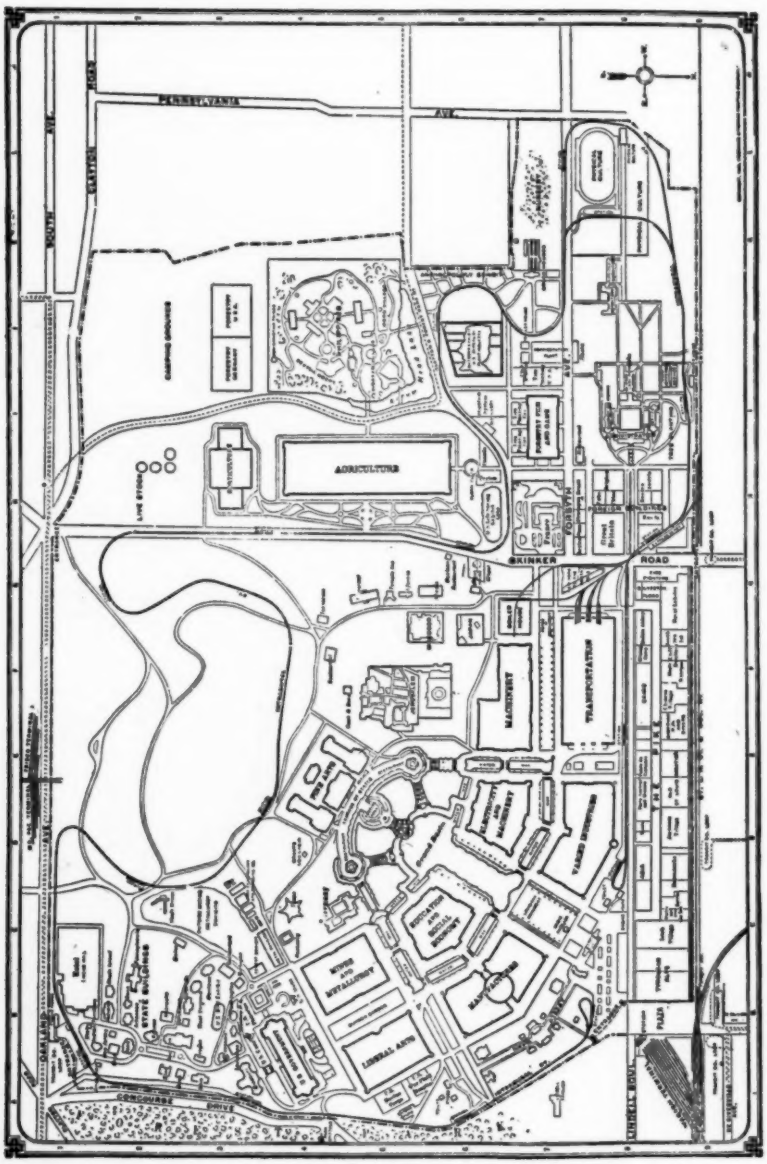
Several of the features of the exposition—such as the exhibit of aerial navigation—for which prizes of the value of $200,000 have been set aside—

are of direct scientific interest. Far surpassing all the rest in this respect is, however, the Congress of Arts and Science, to which we have already called attention. Instead of congresses devoted to each special science, such as have met in connection with other expositions, one great congress has been planned to represent the total accomplishment and unity of science. It is easy to object to certain details of classification and method; but it is evident that a large idea has been conceived and is likely to be successfully realized. The original plan is due to Professor Hugo Münsterberg. The members of the committee visited Europe during the summer to extend invitations to foreign men of science, and at St. Louis during the meeting of the American Association the list of American speakers to be invited was completed. About 125 of the most eminent foreign men of science and scholars have accepted the invitation, and there will doubtless be an equally cordial response from Americans. Professor Münsterberg in an article on the congress in *The Journal of Philosophy* says: "Almost every one of these European scholars has in his own field brought about a certain synthesis of widely separated elements of thought, and has devoted not the smallest part of his work to the fundamental conceptions and methods of his science. The addresses which they will deliver thus lie essentially in the line of their own best thought, and yet it is most probable that the greater part of these addresses would never have been written had not the outer occasion of our



SIMEON E. BALDWIN, Judge of the Supreme Court of Errors, New Haven, Conn., Vice-president for Social and Economic Science.

invitation stimulated them to undertake the task. Such work is too easily postponed. And thus the congress may hope to create in these hundreds of addresses a connected and consistent work which no chance group of individuals would have produced, which demanded a unified program and the enthusiasm of the leading thinkers of the world. But we hope that still more important than the set addresses will be the living influence of this gathering, in which the four or five hundred invited official speakers and chairmen, together with the thousand who may make shorter communications, will form merely the



PLAN OF THE ST. LOUIS EXPOSITION GROUNDS.

nucleus of the international meeting. That such a unique fusion of scholarship will be productive in itself no one can doubt; but that these scholars are brought together and are doing their work under the control of the

PALACE OF EDUCATION AND SOCIAL ECONOMY.

demand for unity in knowledge, for interrelation and synthesis—this thought will be the living force, the most powerful factor of the congress, and a tremendous influence in overcoming the pedantic and unphilosophic narrowness of specialists in every corner of the realm of science."

THE SCIENTIFIC BASIS OF CHEESE MAKING.

THE processes involved in the making and curing of cheese have been the subject of some of the most noteworthy dairy investigations which have been made. While the subject had been studied in a fragmentary way in this country and in Europe for some time, little real progress was made until several of the American experiment stations undertook a systematic investigation of the nature and causes of the changes involved and the chemical character of the products formed. This has gone on steadily for eight or ten years, and has resulted in the working out of the scientific principles underlying this very ancient art. The largest amount of work has been done by the experiment stations in Wisconsin, New York and Canada, and the names of Babcock, Russell, Van Slyke and Hart are especially prominent. The reports of progress have appeared in a series of bulletins from these stations, several particularly important ones having been issued during the past few months.

In the course of the chemical studies the product formed by the action of rennet on milk, about which there had previously been considerable doubt, was identified as paracasein. This was found to combine with acids to form mono- and di-acid salts, quite different in character and in their effect upon the appearance of the curd. In normal cheese making the mono-acid salt is formed, the paracasein uniting in that proportion with the lactic acid produced in the curd by lactic-acid bacteria. These bacteria have invariably been found in the milk and green cheese in predominating numbers, but their true function has remained until now a mystery. They are indispensable to the formation of paracasein monolactate in cheese curd, and this compound is found to be the starting point of the ripening or curing process.

The first step in this appears to be a peptic digestion of the monolactate, the rennet ferment being the active agent. Rennet, which was formerly supposed to contain two enzyms, is found to be in reality a peptic ferment and to act in all essentials like commercial pepsin in forming soluble nitrogen compounds. In fact, normal cheese has been made by the substitution of commercial scale pepsin for rennet extract. The chemical changes produced by both rennet and pepsin are confined mainly to the formation of paranuclein, caseoses and peptones, only small amounts of amids and no ammonia being formed. The action of these enzyms does not appear to ex-

tend to the formation of the compounds that give the flavor to cheese. In normal cheese tyrosin, oxyphenylethylamin, arginin, histidin, lysin, guanidin, putrescin and ammonia were found as end products of the proteolysis. The investigations indicate that the formation of secondary amido compounds and ammonia are due to the action of a biological factor, not yet determined.

The conditions affecting the chemical changes in the ripening process have been worked out in detail, and among these the favorable effect of low temperatures has been demonstrated. The latter is entirely opposed to the views heretofore held by practical cheese makers, who have avoided too great cold, believing it to result in a bitter, inferior product. The advantages of cold curing are shown by an extensive experiment recently concluded by the National Department of Agriculture in cooperation with the experiment stations in Wisconsin and New York. About 500 cheeses representing a great variety of makes were cured at temperatures of 40°, 50° and 60° F., whereas the temperature of ordinary curing rooms runs up to 70° and often higher in summer. The improvement in quality of the cold-cured product was evident in the flavor and texture and in its higher market value. The loss of moisture in cold curing was very much less, resulting in diminished loss from shrinkage; moreover, the cheese can be held a long time at low temperatures without impairment of quality. These investigations will tend to revolutionize cheese making in several respects, by furnishing a scientific basis for it in place of the purely empirical rules and traditions which formerly prevailed, and will simplify the process, rendering possible a more uniform product of improved quality.

SCIENTIFIC ITEMS.

We regret to record the death of Professor Karl Alfred von Zittel, the eminent paleontologist of the University of Munich; of M. Proust, professor of hygiene of the University of Paris and inspector general of the Sanitary Service; of Dr. Eugene Askenasy, honorary professor of plant physiology at the University of Heidelberg; and of Mr. Gurdon Trumbull, the artist and ornithologist, of Hartford, Conn.

Mr. John Morley will deliver the principal address at the opening of the Technical Institution, founded at Pittsburg by Mr. Carnegie, in the autumn of 1904.—Sir William Ramsay, of London, will give a course of lectures during the summer session at the University of California on 'The Constituents of the Atmosphere and the Emanations from Radium.'

Dr. G. W. Hill, of Nyack, N. Y., has been elected a corresponding member in the section of astronomy of the Paris Academy of Sciences.—Professor George W. Hough, of Northwestern University, has been elected an associate member of the Royal Astronomical Society.—The sixtieth birthday of Dr. Robert Koch was celebrated on December 11. A portrait bust was unveiled in the Institute for Infectious Diseases, Berlin, a museum for bacteriology was established and a *Festschrift* is in press.

Mr. Shyamaji Krishnavarma, of India, has offered $5,000 to Oxford University to establish a lectureship in honor of Herbert Spencer to be known as the Spencer Lectureship.

The Nobel prizes, each of the value of about $40,000, were awarded in Christiania, on December 10. The prize in physics was divided between M. Becquerel and M. and Mme. Curie, of Paris. The prize in chemistry was awarded to Professor Arrhenius, of Stockholm; the prize in medicine to Dr. Finsen, of Copenhagen, and the prize in literature to Dr. Björnstjerne Björnsen, of Christiania.—The prize for French contributions to science given by M. Osiris through the Paris Press Association has been divided between Mme. Curie and M. Branly. Mme. Curie receives 60,000 francs for her work on radium and M. Branly 40,000 francs for his work in connection with wireless telegraphy.